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TRIBOELECTRIC TESTING

Final Report

NASA Office of the Chief Engineer
Reliability and Quality Assurance Division
Washington, DC

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Reliability Analysis Center
Rome Air Development Center
Griffiss Air Force Base, NY

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report documents the results of a study in which the objective was to improve the methods and apparatus used to characterize the properties of materials used in Electrostatic Discharge (ESD) Control. The apparatus used was a modified version of the Triboelectric Tester currently in use at the Kennedy Space Center, along with a control unit, electrostatic meter, and a chart recorder. This equipment allowed the electrostatic decay properties of the material to be recorded. Surface resistivities were also measured and correlations made with static decay time. <i>Let equipment test material for test and evaluation.</i>			
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TRIBOELECTRIC TESTING
FINAL REPORT

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Griffiss Air Force Base, NY

Preface

This final report was prepared by the Reliability Analysis Center under Government contract number F30602-81-C-0299 as a part of task 4 of FY'83 Project Plan P-83-003. The study is a continuation of earlier work performed under task 3 of FY'82 project plan P-82-005.

The original task as stated in P-82-005 called for a study of triboelectric test methods and the development and evaluation of a suitable test apparatus intended to measure the effectiveness of electrostatic discharge (ESD) protective work surfaces.

A subsequent literature search revealed that great difficulty would be encountered in attempting to characterize a laminated work surface, the most common form of such items, by first triboelectrically charging the surface and then measuring the inherent charge decay time to zero. In view of the probable impact of this newly acquired information on the projected triboelectric test method as applied to commonly available work surfaces, it was decided to direct the efforts of this task toward the possible improvement of a triboelectric test apparatus designed by and in use at Kennedy Space Center (KSC).

Available documentation of the KSC apparatus was therefore studied and a new apparatus designed and fabricated. Several improvements were incorporated which were intended to facilitate the acquisition of more complete and accurate data than is possible with the original apparatus. The necessary peripheral instrumentation was acquired for purposes of evaluation of the test apparatus and future testing of materials upon request.

A series of tests was performed utilizing samples of material similar to those discussed in a KSC test report in order to compare the operation of the improved apparatus with that of the original. In the course of this evaluation procedure, various phenomena appearing on the recorded charts were noted and analyzed. It is expected that the new

information thus obtained will have considerable impact on the ESD community. Further, the results of certain experiments performed suggest that it may be feasible to test laminated materials in this fashion, provided the peripheral instrumentation can be modified to detect and record the extremely low electrostatic voltage field that remains after all field suppression effects have stabilized.

The comparison tests and subsequent evaluation indicate that the majority of the improvements incorporated into the new apparatus should receive serious consideration as desirable modifications to the KSC apparatus. These modifications, if incorporated, will result in improved performance, ease of operation, increased accuracy of test data, and a broader range of capabilities.

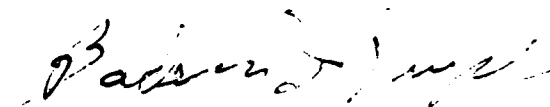
The principal RAC investigators on this program were Bader I. Rupe and William K. Denson.

Approved:



Steven J. Flint
Technical Director

Submitted:



Bader I. Rupe
Project Engineer



William K. Denson
Advisory Engineer

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1.0 SUMMARY

Improvements incorporated into the modified version of the triboelectric test apparatus eliminated many of the problems inherent in the Kennedy Space Center (KSC) equipment. This resulted in the ability to study and analyze many phenomena whose presence were previously unsuspected. Experiments proved that the repeatability of tests was well within reason, indicating that the human error previously involved had been reduced to specimen contamination due to handling which caused slightly different results between specimens taken from the same material sample. This could be further reduced by the imposition of strict handling conditions in a laboratory environment.

It is believed that the improved apparatus is entirely capable of providing accurate characterization of both triboelectric and decay time properties of a large variety of materials, provided the proper peripheral instrumentation is utilized and testing personnel have a thorough knowledge and understanding of the phenomena which will be observed.

Information gathered during the course of this project has already impacted that portion of private industry which supplies electrostatic discharge (ESD) control materials. It can also be expected to lead to significant changes in several existing test methods and military specifications.

The information can also be utilized in the generation of definitive test procedures applicable to a variety of specific materials for which no previously devised test methods currently exist.

2.0 INTRODUCTION

The purpose of this study is to define possible problem areas in the design and operation of a triboelectric test apparatus designed by and currently in use at the Materials Testing Facility at KSC. The

equipment in question is being utilized to evaluate the charge generating characteristics and decay time properties of plastic films under consideration for use as drapery materials and other purposes in areas where an ESD can present a personnel safety hazard. The study is also intended to provide the information necessary to improve the KSC apparatus with a view to increased accuracy of test data and a broader range of application.

The study is the result of an extensive effort which included a thorough analysis of available documentation covering the KSC apparatus, the design and fabrication of a new tester patterned after the original but incorporating many modifications for improved operation, and the testing of many specimens of a variety of materials for purposes of verifying the validity of those improvements.

3.0 SCOPE

The following efforts are included:

3.1 Study of KSC Triboelectric Tester

Available documentation on this apparatus was analyzed and possible problem areas identified for improvement.

3.2 The New Triboelectric Tester

A complete new set of drawings was generated which incorporated modifications designed to correct the problems previously identified. The modified version was then fabricated and tested. Several small problems were identified and corrected during the debugging process.

3.3 Testing Materials

A quantity of materials similar to those covered by a previously published KSC test report was acquired and tested on the improved tester in order to compare the operation of the new apparatus with that of the original.

3.4 Analysis of Specific Recorded Phenomena

Specific chart recordings obtained during materials testing were analyzed to gain an understanding of each of the variety of phenomena which were displayed.

3.5 Analysis of Materials Test Data

All chart recordings obtained during materials testing with the modified apparatus were analyzed and compared with available data from the KSC test report. An attempt was also made to correlate the various decay rates with surface resistivity measurements.

4.0 STUDY OF KSC TRIBOELECTRIC TEST APPARATUS

4.1 Available Documentation

Available documents covering the KSC triboelectric tester were obtained from that facility for evaluation. This documentation consisted of 1) blueprints of the apparatus, 2) a complete test method which also described operating procedures, 3) photographs of the apparatus taken from several angles, and 4) test report MMA-2116-80, dated 15 April 1981, describing the results of tests performed on certain materials by the KSC Materials Testing Facility. The test method, photographs and test report are included as Appendix B.

4.2 Identification of Problem Areas

A study of the documentation revealed the following possible problems which could distort the results of tests performed in accordance with test method instructions.

4.2.1 The uncontrolled time lapse which occurs when specimens are removed from the conditioning chamber and mounted on the apparatus could be allowing drastic changes in the moisture content of materials.

4.2.2 Manual control of rubbing time could cause wide variations in the amount of charge generation from specimen to specimen of the same material.

4.2.3 The rubbing wheel may not attain full speed of rotation prior to contact with specimen.

4.2.4 The heat generated by friction may be dissipating moisture from specimens and causing changes in charge dissipating characteristics, particularly in those the materials which depend on atmospheric humidity for their operating mechanisms.

4.2.5 The permanent hard ground to the sample holder causes considerable discharge time data to be lost between cessation of rubbing and commencement of field measurement.

4.2.6 Extensive handling of specimens prior to the test cycle could result in varying degrees of contamination causing inconsistent changes in characteristics.

4.3 Conclusions

Many of the inherent problems identified above can be minimized or entirely eliminated by changes in the construction and operating control system of the apparatus. Variations in moisture content from one specimen to another can be eliminated by improvements in laboratory facilities.

5.0 THE MODIFIED TRIBOELECTRIC TESTER

5.1 Design and Fabrication

In order to incorporate the desired modifications into the apparatus, a complete new set of drawings was generated. The same physical size and general configuration of the original apparatus was utilized to facilitate possible future modification of that equipment. The apparatus was then fabricated and assembled.

The tester differs from the original version in the following respects:

5.1.1 The swinging arm was fabricated from teflon to isolate the specimen from ground during rub and drop intervals.

5.1.2 A sample holder was designed which could be rapidly mounted on the arm with a minimum of manipulation. Ten of these sample holders were fabricated to facilitate rapid testing of a series of specimens.

5.1.3 A single-pole, single-throw relay capable of handling 30 kilovolts was incorporated into the sample holder grounding circuit to allow precise control of commencement of specimen discharge time.

5.1.4 A DC motor of the exact same configuration and physical size as the original AC motor was substituted to allow infinitely variable rubbing speed control.

5.1.5 An electrical solenoid and an adjustable return spring were incorporated to replace the manually operated motor mount lever.

5.1.6 An adjustable mounting bracket for the voltage field sensor was provided to facilitate variations in spacing between the sensor and specimen for calibration purposes.

5.1.7 A separate control console incorporating power supplies, relays, switches and various other component parts was designed and fabricated to control the operation of many of the above features and the peripheral instrumentation.

5.1.8 Two teflon rubbing wheels were fabricated similar to that used in the original version. Three additional wheels were fabricated which incorporated natural cat fur as the rubbing media. This was to facilitate an investigation into the possible dissipation of moisture due to friction heating of specimens.

5.1.9 A latching mechanism was designed and fabricated to capture and hold the swinging arm after it reaches the measuring position.

5.2 Results of Modifications

The result of the above modifications was to eliminate all manual timing errors from commencement of rubbing to completion of measurement by virtue of entirely automatic operation during that portion of each test cycle. Further, the test apparatus and ten loaded sample holders can be placed within a commercially available humidity controlled glove box and the entire contents conditioned at the desired RH level, thus eliminating the uncontrolled time previously required to remove specimens from the conditioning chamber and mount them on the apparatus.

Electrical interconnections to the control console and the electrostatic voltmeter can be led out via feed-through connectors without compromising the integrity of the glove box. The mounting and dismounting of sample holders on the swinging arm and the few other necessary internal manipulations can be readily accomplished while wearing the heavy gloves normally incorporated into glove boxes.

5.3 Changes in Peripheral Instrumentation

Changes in peripheral instrumentation consisted of the following:

5.3.1 An Electro-Tech Systems Model 102 electrostatic voltmeter was substituted for the Kiethley electrometer as the charge measuring device. The Model 102 is considerably easier to "zero" and incorporates a variable 0 to 1000 VDC power supply which can be connected to the test apparatus for calibration purposes.

5.3.2 A Yokogawa Model 3067 memory chart recorder was substituted for the storage oscilloscope utilized at KSC as the charge decay time recording device. This instrument provides immediate or delayed hard copy of incoming signals which can be readily reproduced for reporting purposes without resorting to film photography. The instrument is capable of recording events on a time base of 10 microseconds per centimeter by virtue of possessing a bandwidth of DC to 50 KHz, a property more than adequate for this application.

5.4 Operating Sequence of Tester

The modified version of the tester operates in the following sequence:

5.4.1 Specimens are mounted in sample holders and conditioned as required by the applicable test method or specification.

5.4.2 A loaded sample holder is mounted on the swinging arm.

5.4.3 The arm is moved manually away from the measuring position toward the rubbing wheel. This movement inhibits the voltage field sensor and applies power to the rubbing wheel motor.

5.4.4 The manual movement of the arm is continued until the sample is located in the rubbing position. This actuates the solenoid which pulls the rotating rubbing wheel against the specimen and locks the arm in place.

5.4.5 The operator removes his hand from the swinging arm. All subsequent actions during the test cycle are controlled automatically by the control console.

5.4.6 An adjustable time delay relay maintains the rotating wheel against the specimen for a preset time interval.

5.4.7 At the end of the preset rubbing time the solenoid is released, the motor return spring retracts the rubbing wheel, and the arm is allowed to swing downward of its own weight towards the measuring position.

5.4.8 The arm locks into position in front of the voltage field sensor stopping motor rotation, enabling the sensor and triggering the memory of the chart recorder.

5.4.9 A second preset time delay relay closes the high voltage relay to commence the discharge of electrostatic voltage present on the sample holder and specimen.

5.4.10 The chart recorder prints the data from memory upon demand by the operator.

5.4.11 The sample holder with specimen is removed from the arm and the entire process repeated for each remaining conditioned specimen.

5.5 Discussion of Tester Operation

Tests performed on a variety of materials have shown that the modified version of the triboelectric tester is capable of producing consistent and repeatable results with a minimum of errors. In addition, it was found that after all ten sample holders had been loaded with specimens of the same material, the entire run could be tested in less than thirty minutes.

It was found necessary to recalibrate the peripheral instrumentation each time a different material was tested to assure that the optimum amount of space on the charts was utilized. This was easily accomplished by experimenting with a representative sample prior to the final run for record purposes.

To facilitate calibration of both the electrostatic voltmeter and the chart recorder, it is recommended that one sample holder be permanently fitted with an aluminum sheet in place of a specimen, and reserved for this purpose.

6.0 TESTING OF MATERIALS FOR EQUIPMENT EVALUATION

To compare the modified tester with the original version, samples of eight of the ten materials covered by KSC test report MMA-2116-80 were acquired from the manufacturers listed in that document. Samples

of "Velostat" and "Lectrolite" were not obtained since their inherently low volume resistivities had resulted in decay curves so fast as to be completely obscured by the drop time of the original equipment and would therefore be useless for comparison purposes.

One sample holder was fitted with an aluminum sheet for use as a calibration fixture. To avoid delays after each calibration process only nine specimens of each material were prepared for testing.

One specimen of each material was tested in accordance with ASTM D-257 to determine its surface resistivity. The nine specimens of each material were then tested in the apparatus using each rubbing media in turn, (see 5.1.8). Temperature and humidity readings were taken at the time of each testing of each set of specimens since all testing was performed without the benefit of a humidity controlled glove box.

The peak voltage values of each set of nine recordings were averaged and the chart from each set displaying a peak nearest the mean was selected for inclusion in this report. Other charts are also included to illustrate discussions of specific phenomena which occur during the testing process. The full ranges of peak voltage values obtained during materials testing are listed in Table I of Appendix A by material and rubbing media.

The KSC test report indicates decay rates for AS 1400 material far in excess of the maximum required by the specification to which it is qualified, MIL-B-81705. It was suspected that friction heat caused by rubbing with teflon had evaporated moisture from the surfaces of the specimens changing their static dissipating characteristics. Cat fur was therefore utilized as an alternate rubbing media to determine if a light pressure rub with a soft electrostatic generating media would produce different decay times than teflon. Charts recorded after rubbing with each media indicated that both decay rates were essentially the same and at least two orders of magnitude faster than the data presented in the KSC report.

Natural cat fur was utilized as an alternate rubbing media in testing all materials involved in the equipment evaluation process to determine whether a "standard" might be established which could replace teflon. If this "soft" media proved successful in this application, it would be quite useful in testing specimens of rigid materials which would not conform to the curved surface of the teflon rubbing wheel. The data obtained was analyzed as explained in paragraph 8.0 of this report.

7.0 ANALYSIS OF SPECIFIC OBSERVED PHENOMENA

7.1 During the course of preliminary testing and debugging of the apparatus and its peripheral instrumentation a number of phenomena were observed on recorded charts. These phenomena are explained in the following paragraphs.

7.2 A chart taken from the PRV-1310 group was selected as Figure 1 to illustrate phenomena which are present to more or less extent on every chart, no matter what material is being tested. The commonality of these events indicate that they are entirely due to the apparatus. The PRV-1310 chart was selected since the timing of certain events during that group of tests had been adjusted to capture the entire picture commencing just prior to enabling the field sensor.

7.2.1 At time "A" rubbing has been completed, the swinging arm has arrived in the measurement position, and the recorder memory has triggered.

7.2.3 At time "B" the voltage sensor is enabled. The ≈ 25 ms slope between times "B" and "C" is the time required for a rotary solenoid located in the sensor to move a shutter to the full "open" position. The slight notch at the peak is caused by shutter bounce.

7.2.4 The slope between the final peak and time "D" is attributed to sharp corners on the specimen causing corona discharge. Experiments revealed that this slope leveled out at about 3 KV.

7.2.5 At time "D" the high voltage relay closed, shorting the sample holder to ground. The sudden sharp drop in voltage to time "E" is due to the field suppression effects of the grounded sample holder and a glass fibre "screen" embedded within this material. Such fibres are known to be somewhat hygroscopic. This would cause them to be slightly more conductive than the surface layer resulting in enhancement of the field suppression effect of the sample holder.

7.2.6 At time "E" all field changes due to suppression effects have ceased. The entire remaining curve is due to the decay rate of the surface of interest. Since this curve is a decaying exponential, it can be defined as:

$$\tau = \frac{t_1 - t_2}{\ln \left(\frac{V_2}{V_1} \right)}$$

with 5τ being the time necessary for the charge on the surface of interest to decay from any voltage to $\approx 1\%$ of that voltage in the absence of any field suppression effects. Calculations made from several portions of the illustrated curve consistently result in a τ value of 150 ms with 5τ then being 750 ms, indicating that a charge of any voltage placed on the surface of this material will, when grounded, decay to $\approx 1\%$ of its original value in 750 ms, given the same dimensions and configuration of specimen and equipment. This is further explored in paragraph 7.5.

7.3 Figure 2 illustrates an experiment performed to determine the difference between the effects of a grounded and an ungrounded sample holder. A specimen of highly resistive material was selected to minimize the effects of sample discharge. The specimen was charged through normal procedures and then dropped to the measuring position. The high voltage relay closed and was caused to re-open after about 3 seconds. About 1.5 seconds later, the relay was again closed and remained so for the remainder of the recording.

The first closure caused the measured voltage to drop suddenly from a peak of 11.4 KV to 10.1 KV. When the relay re-opened the voltage jumped to 10.5 KV. It can be assumed that if the relay had remained open for the entire ten seconds a straight line would have been recorded, remaining essentially at 11.4 KV. It can also be assumed that the sample holder itself received some charge during the rubbing process. When the sample holder was initially grounded this charge disappeared and the voltage field emanating from the specimen was partially suppressed toward the sample holder. When the holder was then ungrounded the measured voltage increased by about 400 volts, indicating the difference in suppression effects of a grounded vs. ungrounded holder. Note the slight RC time curve at each HV relay closure point.

7.4 Observation of the above mentioned RC times prompted an experiment to determine the capacitance inherent in the sample holder and swinging arm. Figure 3 illustrates this experiment. Twenty megohms of resistance in series with 10 kilohms was connected between the empty sample holder and ground with the input of the chart recorder connected across the 10K resistor. 1000 VDC was applied to the sample holder through the HV relay and the chart recorder calibrated accordingly. The HV relay was then opened, triggering the recorder and allowing the inherent capacitance to discharge through the resistance network to ground. The time required for the voltage to decay from 840 volts to 37% of that value resulted in a calculated capacitance of 38.5 picofarads. This test was repeated with the metal calibration plate mounted in the holder. No discernible difference in the τ value resulted, indicating that the inherent capacitance would remain essentially the same in either the presence or absence of a specimen. This could vary slightly depending on the proximity of the field sensor to the specimen.

7.5 As a result of the data described in paragraphs 7.2.6, 7.3 and 7.4 it was determined that when a readable decay curve has been recorded, it is possible to define the entire curve from any portion thereof. Referring to Figure 24, it can be seen that not only can it be

difficult to determine the decay rate commencing at V_0 and t_0 (depending on the steepness of the curve in that area), but the curve theoretically continues to infinity without ever quite arriving at zero.

Since a decaying exponential can be defined as:

$$V(t) = V_0 e^{-\frac{t}{\tau}}$$

where τ is the time necessary for the voltage to decay to $\approx 36.8\%$ (or $\frac{1}{e}$) of any arbitrary point on the decay curve, then the arbitrary points V_1 and V_2 can be defined as:

$$V_1 = V_0 e^{-\frac{t_1}{\tau}}$$

and

$$V_2 = V_0 e^{-\frac{t_2}{\tau}}$$

Combining the two formulas results in:

$$\frac{V_1}{V_2} = \frac{V_0 e^{-\frac{t_1}{\tau}}}{V_0 e^{-\frac{t_2}{\tau}}}$$

or

$$\frac{V_1}{V_2} = e^{\left[-\frac{t_1}{\tau} - \left(-\frac{t_2}{\tau} \right) \right]}$$

Hence,

$$\frac{V_1}{V_2} = e^{\left(\frac{t_2}{\tau} - \frac{t_1}{\tau} \right)}$$

Since $t_2 - t_1 = \Delta t$, a change in time, then:

$$\frac{V_1}{V_2} = e^{\frac{\Delta t}{\tau}}$$

Taking the natural log of both sides results in:

$$\ln\left(\frac{V_1}{V_2}\right) = \frac{\Delta t}{\tau}$$

or

$$\tau = \frac{\Delta t}{\ln\left(\frac{V_1}{V_2}\right)}$$

Since $\ln\left(\frac{V_1}{V_2}\right) = -\ln\left(\frac{V_2}{V_1}\right)$

then $\tau = \frac{\Delta t}{-\ln\left(\frac{V_2}{V_1}\right)}$ or $\tau = \frac{-\Delta t}{\ln\left(\frac{V_2}{V_1}\right)}$

Since $t_1 - t_2 = -\Delta t$

then $\tau = \frac{t_1 - t_2}{\ln\left(\frac{V_2}{V_1}\right)}$

Because V_2 is always smaller than V_1 and the natural log (\ln) of a number less than 1 is a negative value, the negatives will cancel and result in a positive time constant or τ value.

It should be noted that the above formula is independant of actual voltage values. It is only necessary to display the curve on a linear grid having a known time base and "zero" reference level. From those data the τ value can be calculated. The value 5τ has long been accepted by the electronics industry as the time necessary for a decaying exponential to arrive at "zero" for all practical purposes. This practical "zero" is defined as being approximately 1% (precisely .006737946999) of any arbitrary beginning point on the voltage axis of the curve.

Any convenient point on the curve can be designated as " V_1 " and another convenient point occurring later in time can be designated as " V_2 ". It is absolutely necessary to know exactly where "0" voltage on the recorded image actually is in order to establish the relationship (ratio) between V_1 and V_2 .

Some difficulty has been encountered in establishing a firm zero point to which the measuring instrument will return after each event.

This can be overcome by causing the recorder to draw a second line on the same chart after all changes in input voltage have ceased. This second line is then utilized as the "zero" reference from which the calculations for τ are made.

It is evident that most currently available instruments designed to measure electrostatic field strength have difficulty in returning to calibrated zero after experiencing large voltage offsets. This causes problems in the measurement of final values which are quite low in comparison to the field present at the initiation of measurement.

It is believed possible to design circuitry which will inhibit probe input to the ETS 102 until such time as the field strength arrives at a reasonable level, thereby avoiding the inherent shift in the calibrated "zero". This modification should enable the characterization of the surface layers of laminated materials wherein a buried layer is the most conductive. Measured values could then be limited to the portion of the curve remaining after all field suppression effects have ended, permitting expansion of the curve to obtain much greater resolution.

8.0 TEFLON VS CAT FUR AS THE RUBBING MEDIA

All specimens were rubbed with both cat fur and teflon rubbing wheels to determine whether a "soft" media might be more appropriate as a standard. The recorded data was statistically analyzed to determine which of the two media exhibited the lower variance in measured voltages. Figure 4 depicts all peak voltages obtained on all specimens of each material plotted on a logarithmic scale. It is evident that the first three of the eight materials tested displayed highly significant variance differences. Data obtained from the remaining five materials can be considered insignificant. For the three significant materials, Teflon as the rubbing media resulted in much less variance in peak voltages. Figure 5 is a histogram compiled from the data obtained from Aclar 22A and is offered as an example of the difference in scatter of data points obtained with the two rubbing media. It must be concluded

that Teflon is preferable as a rubbing media to obtain more consistent results. A rubbing wheel can easily be designed utilizing a thin Teflon sheet over a foam rubber backing in the event it is desired to test a hard inflexible material.

9.0 ANALYSIS OF TEST RESULTS

The following is a detailed analysis of the test results as exhibited by the selected representative charts for each material. Note that each referenced chart is annotated with a surface resistivity value and the temperature and relative humidity of the test environment. The surface resistivity measurements were taken utilizing an Electro-tech Systems Model 802 surface resistivity probe in conjunction with a Dr. Kamphausen MILLI-TO Meter in an attempt to establish a correlation between surface resistivity and charge decay rates.

It was found that when the teflon rubbing media was utilized there was a tendency for specimen material to become deposited on the teflon resulting in confused measurement indications. The teflon wheel was therefore cleaned with methyl alcohol after each rubbing operation, correcting this problem.

It was also found that those specimens having an extremely high surface resistivity could have a residual charge when mounted on the tester, preventing proper zeroing of the measurement instrument. This was corrected by spraying both surfaces of each specimen with equal amounts of positive and negative ions from a hand-operated piezo-electric static eliminator immediately prior to the zeroing operation.

It is recommended that in the event a glove box is being utilized, an internal blower be arranged to circulate air through a nuclear ionizing orifice upon demand. This would provide the benefit of maintaining zero charge levels within the chamber except while a test cycle was in progress. It would be necessary to turn the blower off and allow the ions to dissipate before the test cycle was initiated.

It should be noted that when a material specimen exhibits a positive charge it is located above the rubbing media on the tribo-electric series. If a negative charge is detected the opposite is true.

9.1 Aclar 22A (Figures 6 and 7)

Data for this material furnished in KSC test report MMA-2116-80 appears to exhibit several anomalies. Note that Tables 1 and 2 of that document indicate that negative charges were achieved while Tables 3 and 4 indicate positive charges. This was probably due to the fact that Aclar is a form of teflon as was the rubbing media and the polarity of measured charge could be either positive or negative. Also note that Tables 1 through 4 indicate little, if any, charge decay while Table 5 indicates decays of 3 and 5 KV within 5 seconds. This can be explained by the fact that the insulation properties of teflon are drastically reduced by exposure to solar radiation. All Table 5 specimens had been exposed to Florida beach weather conditions for a period of three weeks.

Table 5 also indicates a discharge from a positive value through zero to a negative value at the end of decay time measurement. This was most certainly due to instrumentation problems and had nothing to do with the specimens under test. Specimens 1 and 2 of this material as indicated in Table 5 could be characterized as having decayed 5,200 and 3,200 volts, respectively, over a period of 5 seconds.

Figures 6 and 7 of this report agree quite well with Tables 1 through 4 of the KSC report by exhibiting no loss of charge over a period of 4 seconds. This is typical of materials having surface resistivity values in excess of 10^{15} ohms per square.

9.2 Capran 980 (Figures 8 and 9)

This material, a form of nylon, exhibited only a slight charge decay over a period of 4 seconds at a relative humidity of 28%. The KSC test report indicates a faster decay at higher humidities. The data agree with the known hygroscopic characteristics of most nylons and with the measured surface resistivity of the material.

9.3 Capran 512H (Figures 10 and 11)

Test results obtained with this material were essentially the same as in para. 9.2. Note the slightly enhanced charge decay which is attributed to a higher humidity in the test environment. The lack of significant charge decay agrees with the measured surface resistivity.

9.4 Electro-Safe (Figures 12 through 14)

This material is a clear vinyl with a grid of carbon-like substance applied to one surface in the pattern illustrated in Figure 12. The opposite surface exhibited a resistivity of 3×10^{14} ohms per square. The specimens were mounted in the sample holders such that the bare surface faced the rubbing media. Note in Figures 13 and 14 the differing charge amplitudes achieved with the two rubbing media. Note also the extremely large voltage reductions which occurred when the HV relay grounded the sample holders. This large voltage step is due to the field suppression effect of the carbon grid added to that of the metal sample holder. It must be assumed that a much higher initial charge voltage would have been indicated in the KSC Test Report had the specimens been isolated from ground until after commencement of measurement. It can be further assumed that had the carbon completely covered the reverse side of the material the voltage would have arrived at zero in only the time necessary for 38.5 pF to unload through a very low resistance value. Taking these assumptions into consideration, it can also be assumed that near initial charge was actually present on the specimen in the first millisecond after grounding but the measured field emanating therefrom was being drastically but not completely suppressed by the carbon grid. The discharge curves displayed are commensurate with the measured surface resistivity.

9.5 PRV-1310 (Figures 15 through 17)

This material was apparently changed from the original in that it was blue in color and the reinforcing material buried between the vinyl layers was a glass fibre screen in about a 1/8 inch grid pattern. This

material exhibited well-defined decay curves, arriving at zero from several thousand volts in well under 1 second. This is commensurate with the measured surface resistivity of 5.3×10^{12} ohms per square.

The rather pronounced voltage step at grounding time is attributed to the known hygroscopic characteristics of fibre reinforcement material imbedded into plastic resins. The moisture content of the fibres causes them to be slightly more conductive than the surface layers, resulting in enhanced field suppression effects. Note that this phenomenon is somewhat less in this material than in that described in para. 9.4.

One specimen was reversed in the sample holder and retested to determine if both surfaces had similar characteristics. Figure 17 illustrates close agreement with Figure 16. All recordings generally agree with the KSC test report.

9.6 RCAS - 2400 (Figure 18 through 20)

This material is a pinkish-orange nylon which is entirely dependent on the hygroscopic properties of nylon for its antistatic properties. No surfactants are added as in MIL-B-81705, Type II materials. (see para. 9.8). Tests performed on this material agree quite closely with the KSC test report. In addition to rubbing with both cat fur and teflon, a third test was performed. A sample of the same material was tightly mounted over the surface of the teflon wheel and used as the rubbing media. Figure 20 illustrates that this material is capable of acquiring extremely high charges when rubbed against itself. The nine specimens tested during this phase went consistently negative in polarity. This phenomenon is not fully understood but could be due to the presence of the teflon rubbing wheel and/or the fact that the rubbing media was grounded to the test apparatus during the rubbing process.

All data indicate that this material is unsuitable for use in areas where electrostatic discharges may present a hazard to personnel or equipment unless the relative humidity is in excess 50%.

9.7 Saran 18L (Figures 21 and 22)

Tests performed on this material resulted in essentially flat curves and were in agreement with the KSC report. The data is commensurate with the measured surface resistivity.

9.8 AS 1400 (Figures 23 and 24)

This material is a qualified product in accordance with MIL-B-81705, Type II. The electrical characteristics of the material are dependent on the attraction of moisture from the atmosphere by a special agent incorporated into the resin mix prior to extrusion. The operating mechanism is therefore highly dependent on the relative humidity at the time of use.

Data exhibited in Figures 23 and 24 indicate faster decay times than is evidenced in the KSC test report. A recent study (Gary O. Head, Lear Siegler, Inc., EOS-4, p. 120) indicates that exposure of this material to the atmosphere for several months can result in leaching of the moisture attracting agent to the extent that the surface conductivity is drastically reduced at commonly encountered relative humidity levels. The age of the AS 1400 covered by the KSC test report is unknown but may account for the discrepancy in decay time. It is also possible that excessive rubbing wheel speed and/or pressure may have caused moisture evaporation due to friction heating.

The decay times exhibited in Figures 23 and 24 are commensurate with the measured surface resistivity of the material.

10.0 CONCLUSIONS

10.1 The test results discussed in paragraphs 9.1 through 9.8 generally agree with the data contained in the KSC test report. It is apparent that the more complete and accurate data obtained utilizing the modified version of the triboelectric tester demonstrates the success of the incorporated improvements. The inclusion of the entire discharge curve in the recorded data drastically increases the ability to render a meaningful analysis of test results.

10.2 The observation of field suppression effects clearly indicates the need to define decay curves by the method set forth in paragraph 7.5. It has been postulated that the decay rates of some materials may be voltage dependent (i.e., the higher the voltage the faster the rate of decay). This writer has not encountered a material which possesses this property. It is believed that if and when such a material emerges, a slight modification to the tester will result in the capability of applying a fixed voltage of low value directly to the specimen, providing a means of measurement of decay time at a level below the point where voltage amplitude becomes a factor.

10.3 A direct correlation between charge decay rates and surface resistivity values has been established. The data clearly indicate that the greater the value of surface resistivity, the longer the decay time will be.

10.4 The data obtained when RCAS 2400 was rubbed against itself (para. 9.6) indicates that it may be desirable to test certain materials in this manner, particularly when they are intended for use as drapery materials in explosive situations. A disastrous incident which occurred at KSC a number of years ago was traced to the accidental squib ignition of a rocket motor mounted on a test stand within a building. The squib was activated by an ESD which occurred when a plastic drape was allowed to unroll to cover the equipment under test. It is the understanding of this writer that several fatalities resulted from that incident.

10.5 The data obtained indicates that since the decay time properties of certain materials are somewhat dependent on relative humidity, such items should be conditioned and tested at the lowest relative humidity which can be expected in the use environment.

11.0 RECOMMENDATIONS

11.1 It is recommended that the original KSC tester be modified to incorporate the several improvements embodied in the new tester. It

is also suggested that a SPDT HV relay be utilized in lieu of the SPST relay. This will enable testing by means of an external high voltage power supply in situations where it is not desired to use the triboelectric feature of the apparatus. A voltage rating of at least 25 KV for this relay is recommended.

11.2 Due to the difficulty in maintaining a fixed relative humidity in an entire room, it is recommended that a humidity controlled glove box of sufficient size to contain the test apparatus and all sample holders be utilized when specific relative humidities are a requirement of the test method.

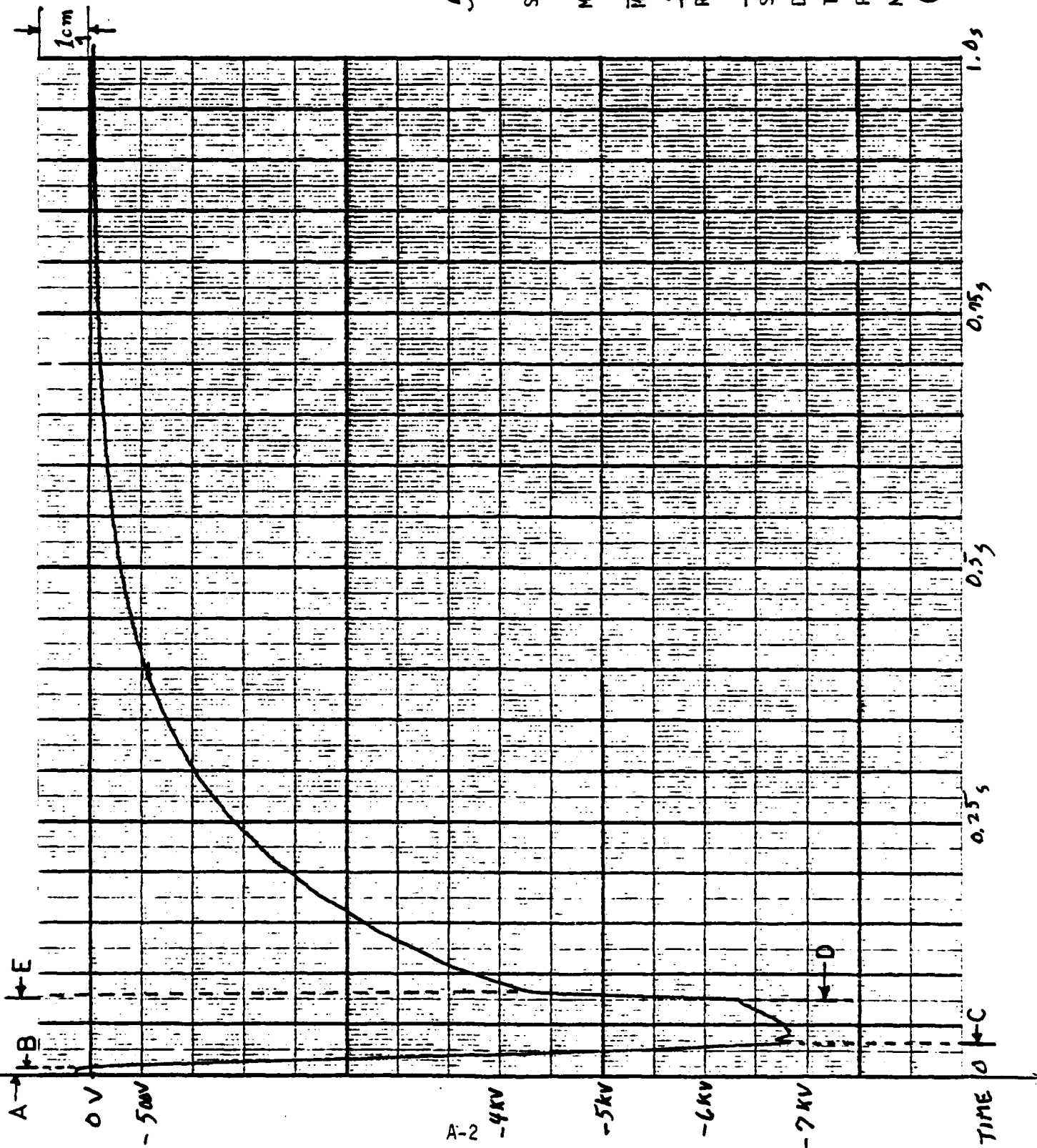
11.3 It is recommended that accept/reject criteria for the decay time of materials be based on the decay time constant TAU (τ) calculated from that portion of a recorded decay curve remaining after all field suppression effects have stabilized (see para. 7.5). The basic formula which should be utilized is $\tau = (t_1 - t_2) / \ln(V_2/V_1)$ where V_1 is the voltage present at a selected time t_1 and V_2 is the voltage present at a selected later time t_2 . 5τ should be considered the decay time to "zero" from the instant of grounding after a static charge of any value is placed by whatever means on the surface of an isolated specimen, given fixed dimensions of electrical contact of the specimen with the sample holder and a fixed physical relationship of the specimen with all objects in the near vicinity. Classically, $\tau = RC$, where R is the equivalent series resistance and C is the capacitance inherent in the discharge path. For test apparatus configurations other than this one, the capacitance C of the specimen must be specified if R is to be inferred from τ . It is evident that any test method involving decay time calculations should be quite specific with regards to dimensional considerations.

APPENDIX A

ILLUSTRATIONS TO THE TEXT

TABLE I - MAXIMUM AND MINIMUM PEAK CHARGE VALUES OBTAINED
DURING EVALUATION TESTS

SPECIMEN MATERIAL	RUBBING MEDIA	PEAK CHARGE	
		HIGHEST	LOWEST
ACLAR 22A	CAT FUR	-16.4 KV	-4.8 KV
CAPRAN 980	CAT FUR	24.8 KV	5.0 KV
CAPRAN 512H	CAT FUR	-1.6 KV	-550 V
ELECTROSAFE	CAT FUR	-820 V	-625 V
PRV 1310	CAT FUR	-7.4 KV	-5.4 KV
RCAS 2400	CAT FUR	9.5 KV	5.0 KV
SARAN 18L	CAT FUR	-4.8 KV	-3.25 KV
AS 1400	CAT FUR	-1.1 KV	-640 V
ACLAR 22A	TEFLON	14 KV	10 KV
CAPRAN 980	TEFLON	11 KV	6 KV
CAPRAN 512H	TEFLON	8.2 KV	5.7 KV
ELECTROSAFE	TEFLON	3.9 KV	3.0 KV
PRV 1310	TEFLON	4.1 KV	2.6 KV
RCAS 2400	TEFLON	14.2 KV	4.5 KV
SARAN 18L	TEFLON	12.2 KV	7.3 KV
AS1400	TEFLON	2.9 KV	2.0 KV



03.02

13:47

1 = 0.1 V/CM

50MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 1

$\tau = 0.155 \text{ s}$

$5\tau = 0.777$

SAMPLE # 1

MATERIAL:

PRV-1310

MANUFACTURER:

SNYDER

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

D-257 : $5.5 \times 10^{12} \Omega/\square$

TEMP.: 22 °C

REL. HUM.: 29.5 %

MEASURED VOLTAGE

(VERT): 500 V /cm

1 cm

03.14

14:33

1 = 50 NV/CM

500 MS/CM

50 DATA/CM

TRG P 0 CM

FIGURE 2

$\tau = 16 \text{ min}$

$5\tau = 1 \text{ hr}, 20 \text{ min}$

SAMPLE # 9

MATERIAL:

ACLAR 22 H

MANUFACTURER:

ALLIED

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

D-257: $2 \times 10^{15} \text{ } \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 38 %

MEASURED VOLTAGE

(VERT): 1 KV /cm

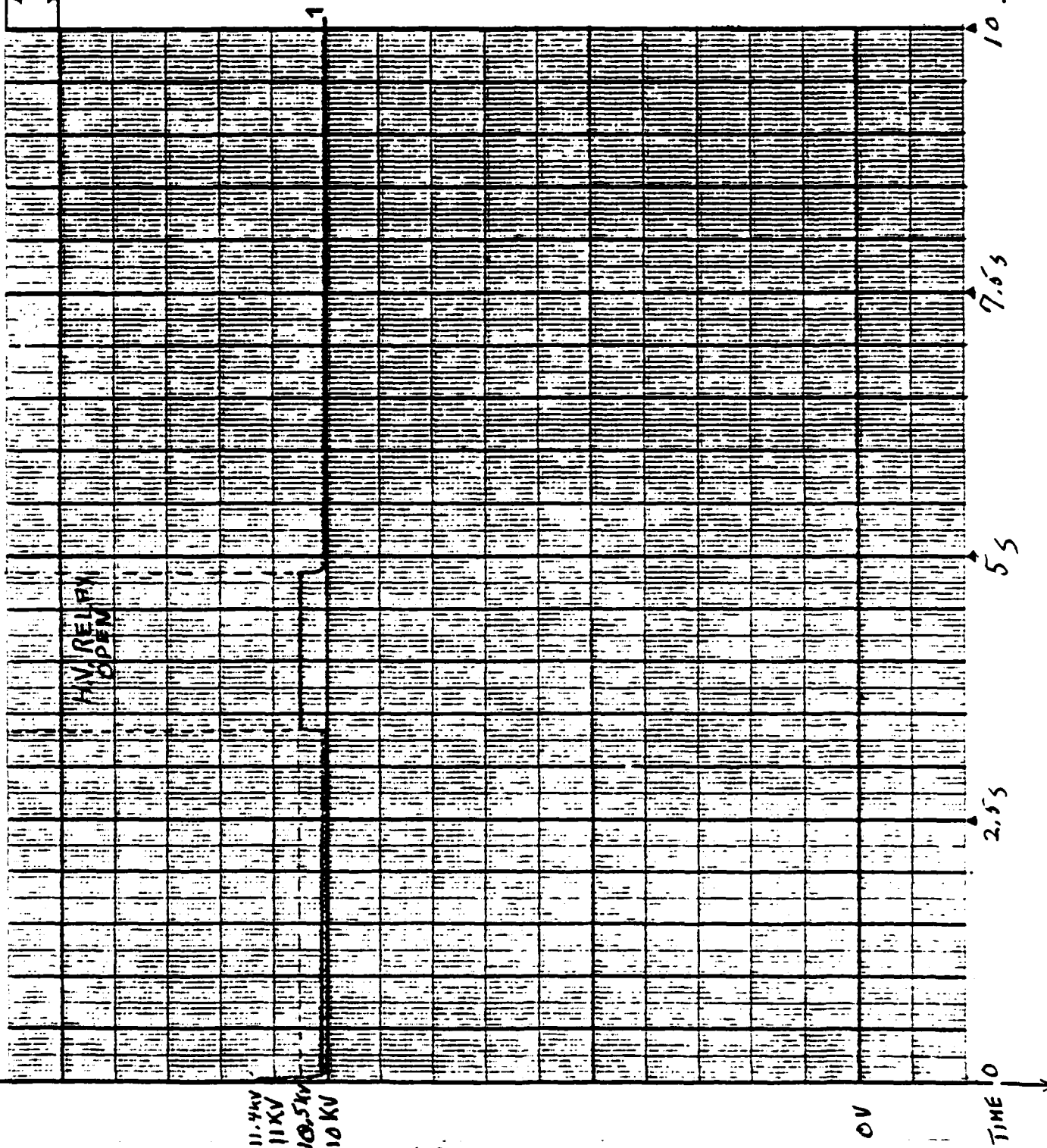


FIGURE 3

01.01

01:57

1FC= 50MV/CM

100US/CM

10 DATA/CM

TRC P 0CM

EMPTY SAMPLE HOLDER
MOUNTED, CHARGED TO
1000 VOLTS, THEN
DISCHARGED THROUGH
20.4 MEGOHMS TO
GROUND.
 $\tau = 7.7 \times 10^{-4}$ SEC.
 $C = 38.5$ PF
SAMPLE #

MATERIAL:

MANUFACTURER:

RUBBING MEDIA:

SURF. RES. IAW ASTM

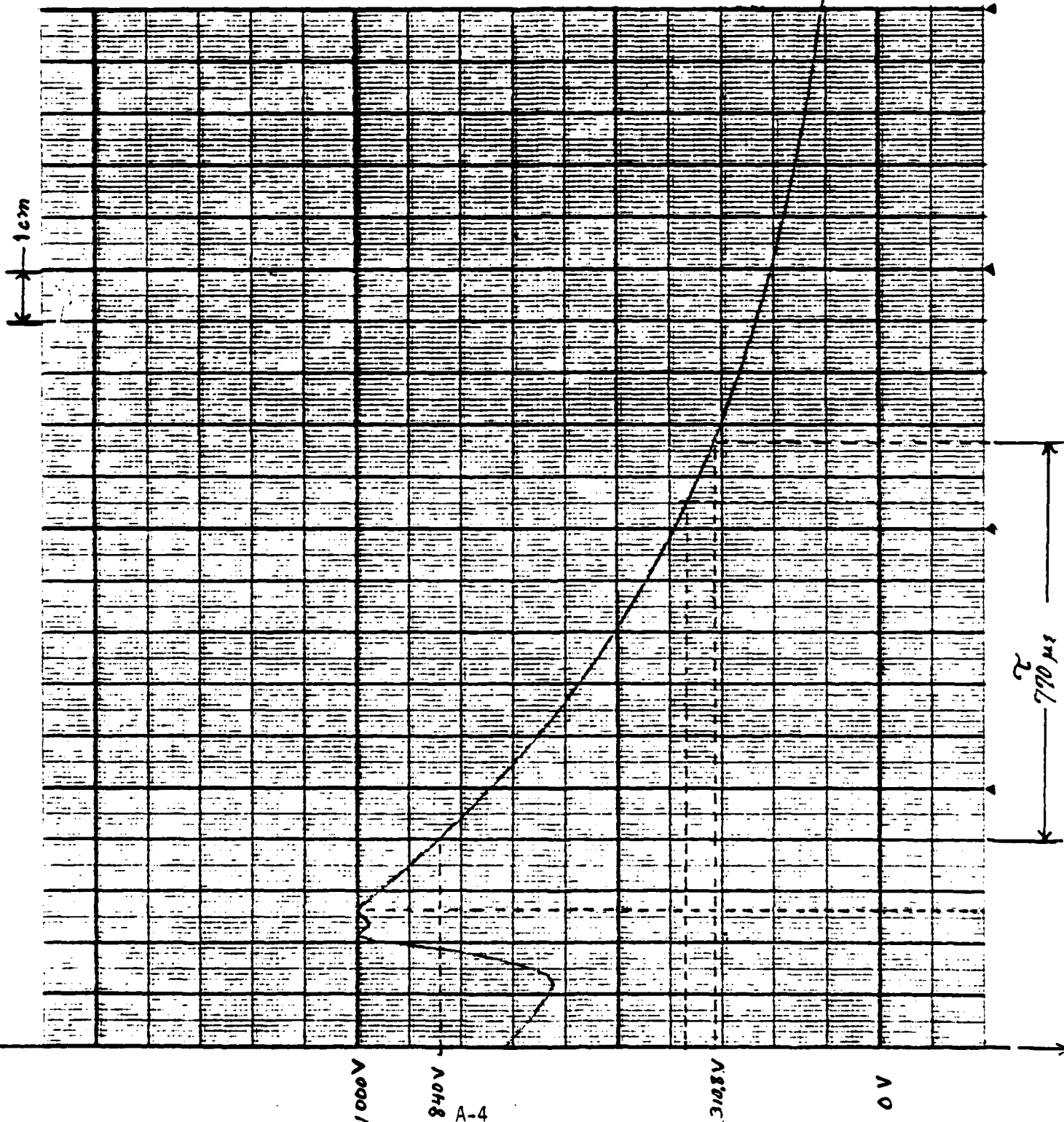
1FC-257: $\frac{\Delta V}{D}$

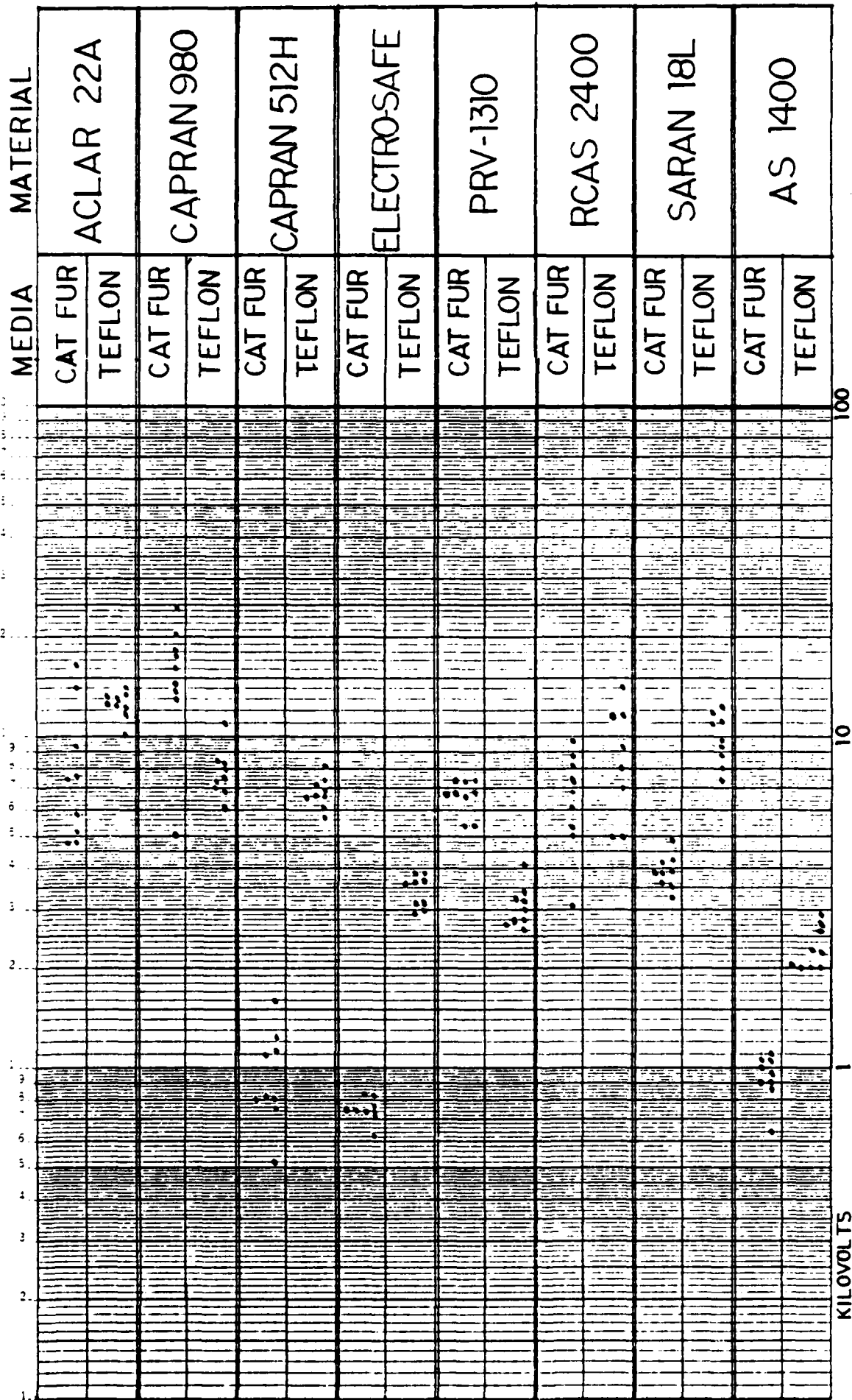
TEMP.: $^{\circ}\text{C}$

REL. HUM.: $\%$

MEASURED VOLTAGE

(VERT): 100 V/cm

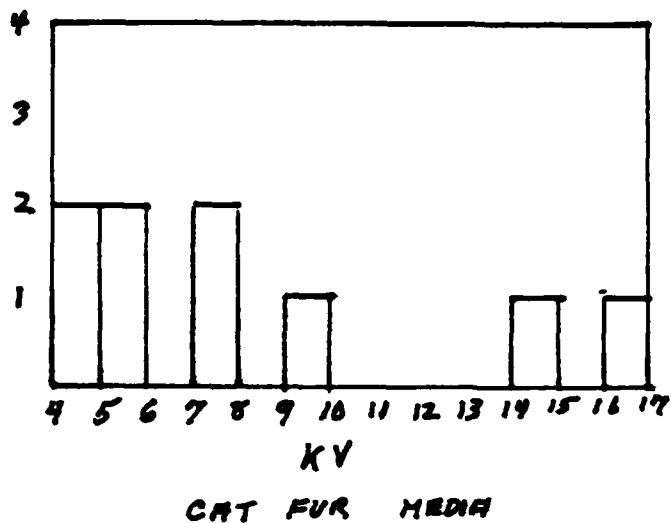




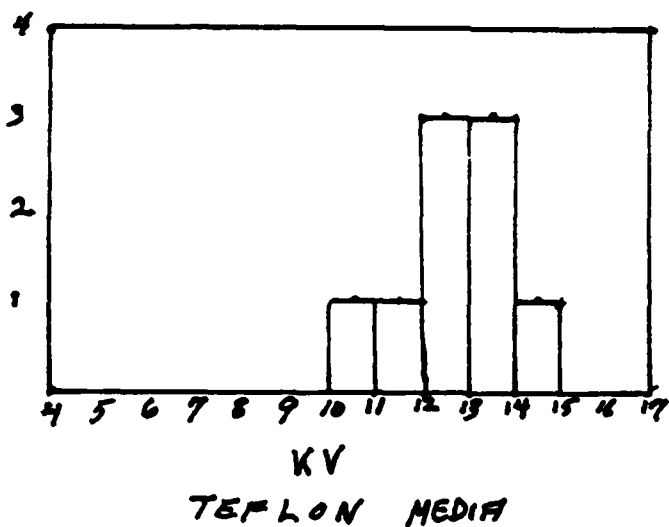
PEAK VOLTAGES ATTAINED RUBBING WITH CAT FUR VS TEFLON

FIGURE 4

DATA
POINTS

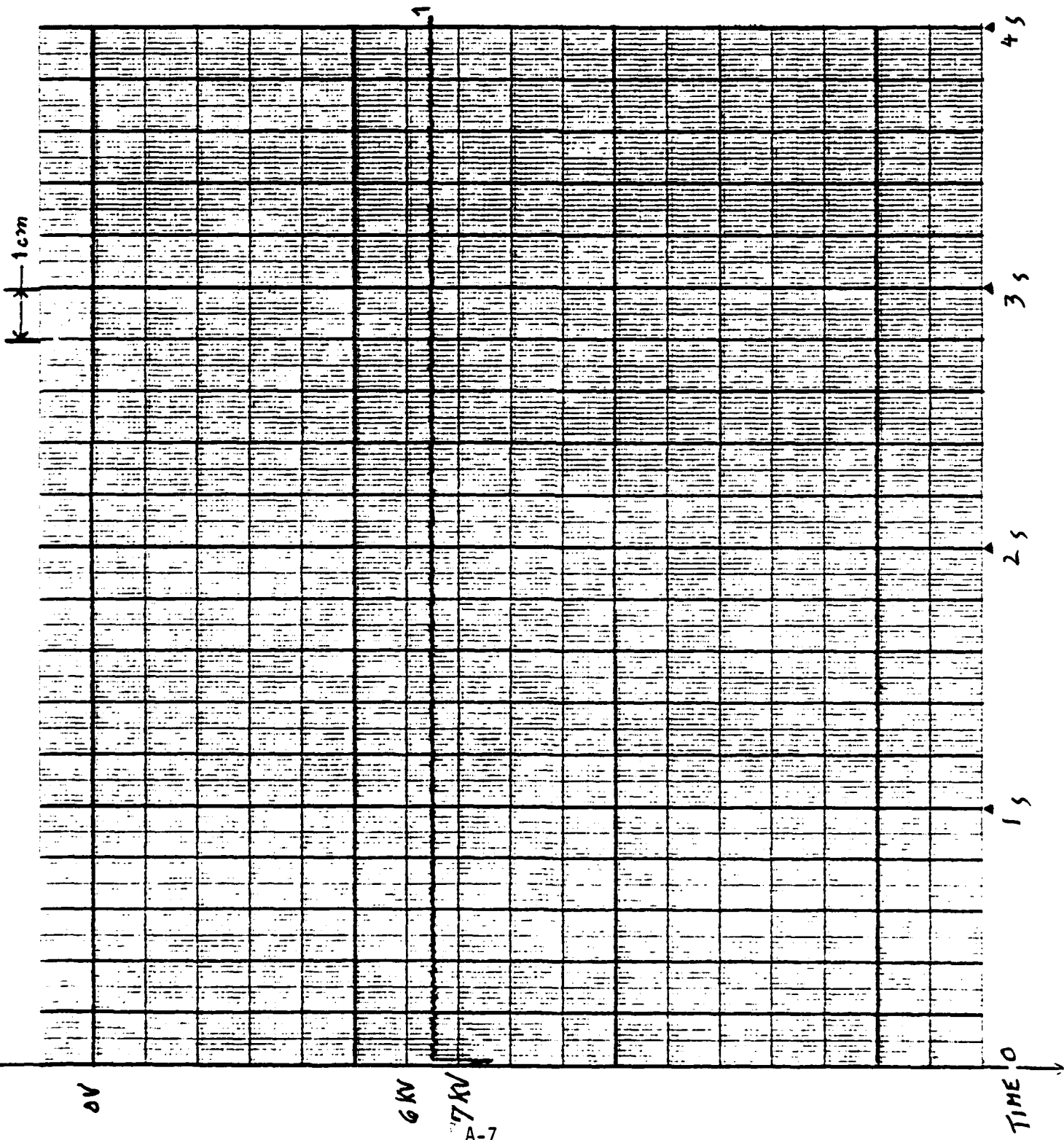


DATA
POINTS



PEAK VOLTAGES ATTAINED RUBBING WITH CAT FUR VS TEF LON
MATERIAL ; HCLAR 22M

FIGURE 5



03.14

13:12

1 = 50MV/CM

200MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 6

$\tau = 4 \text{ min}$

$5\tau = 20 \text{ min}$

SAMPLE # 8

MATERIAL:

ACLAR 22A

MANUFACTURER:

ALLIED

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

D-257 : $> 2 \times 10^{15} \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 38 %

MEASURED VOLTAGE

(VERT): 1KV/cm

03.14

14:23

1 = 50MV/CM

200MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 7

SAMPLE # C

MATERIAL:

ACLAR 22 A

MANUFACTURER:

ALLIED

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

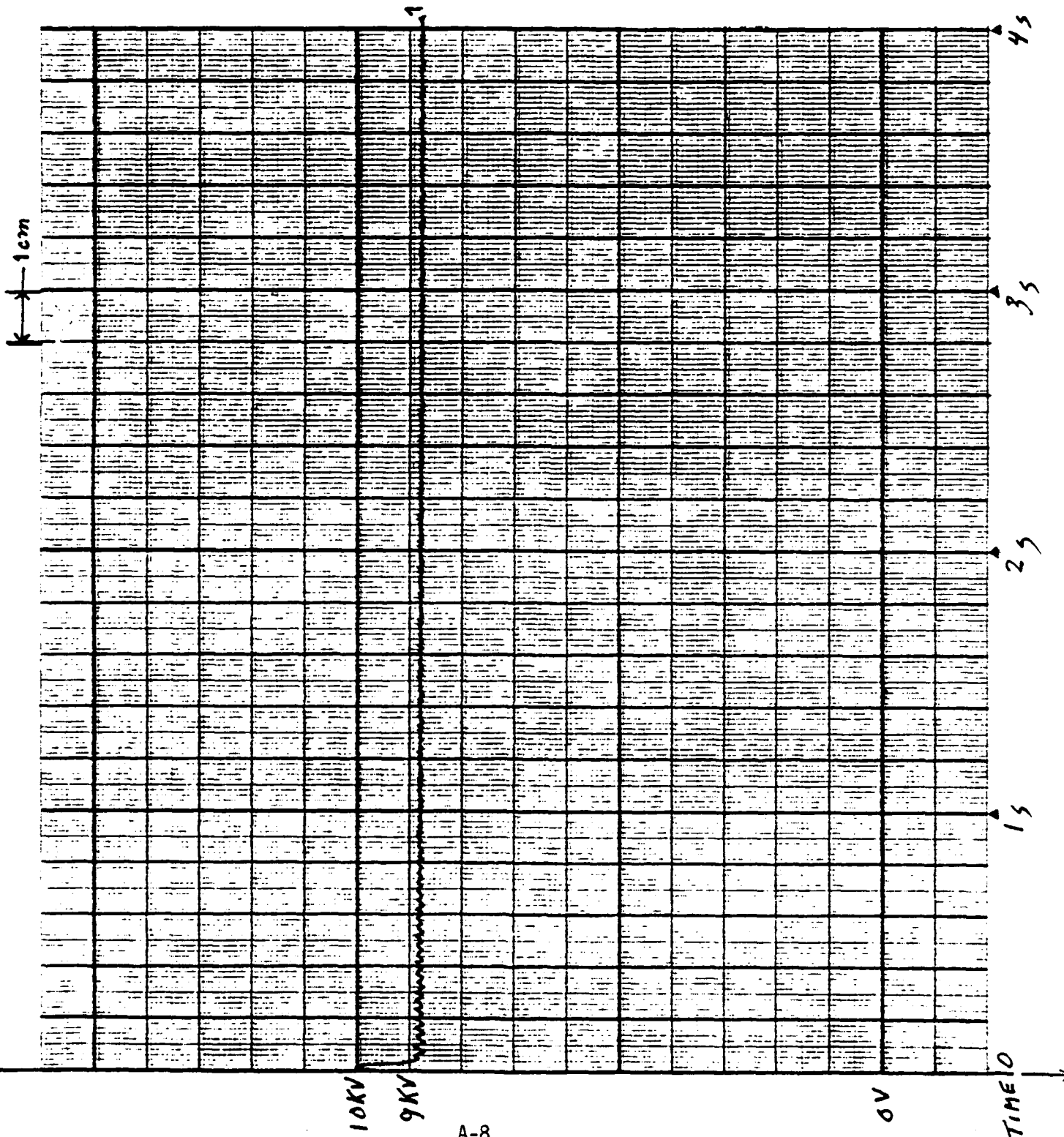
D-257 : $> 2 \times 10^{15}$ Ω/\square

TEMP.: 23 °C

REL. HUM.: 38 %

MEASURED VOLTAGE

(VERT): 1 KV/cm



1cm
↑

02.28

15:16

1 = 0.1 V/CM

200MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 8

$\tau = 3 \text{ min}, 20 \text{ sec}$

$5\tau = 17 \text{ min}$

SAMPLE # 5

MATERIAL:

CHPPAN 980

MANUFACTURER:

ALLIED

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

D-257 : $> 2 \times 10^{15} \Omega/\square$

TEMP.: 24 °C

REL. HUM.: 28 %

MEASURED VOLTAGE

(VERT): 2KV /cm

02.28

15:57

1 = 50MV/CM

200MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 9

SAMPLE # 5

MATERIAL:

CARBON 980

MANUFACTURER:

ALLIED

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

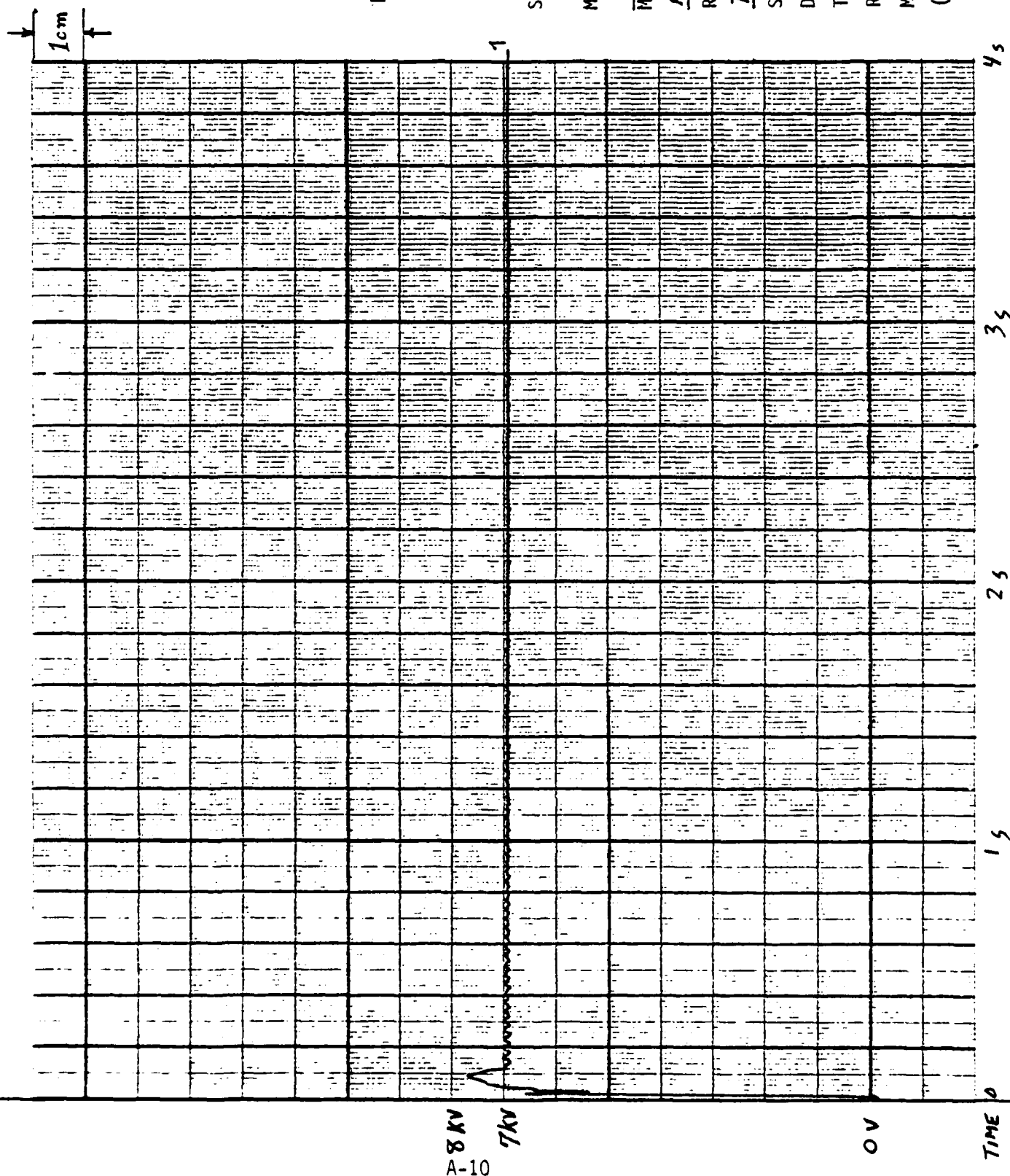
D-257 : $> 2 \times 10^{15} \Omega/\square$

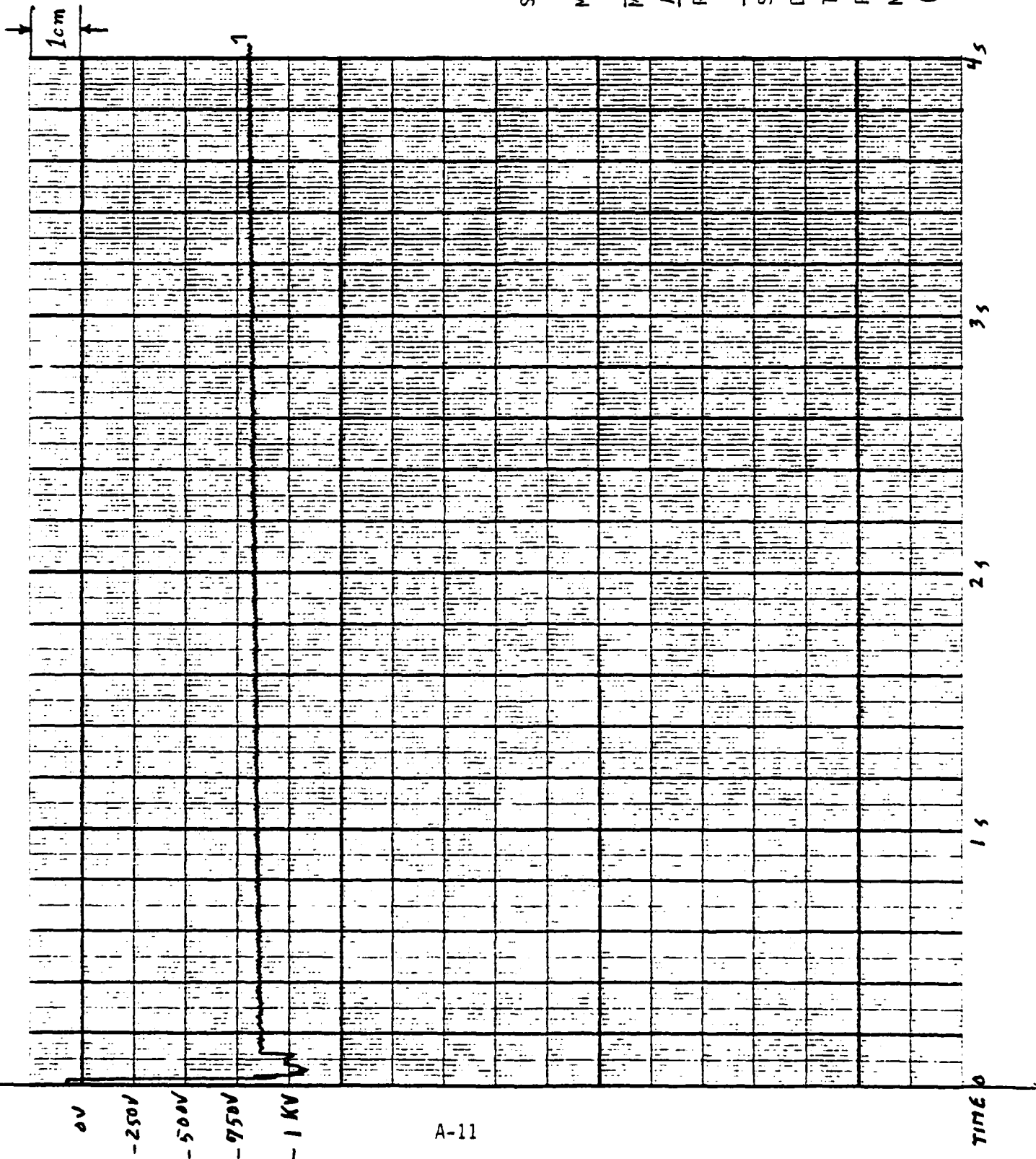
TEMP.: 24 °C

REL. HUM.: 28 %

MEASURED VOLTAGE

(VERT): 1KV/cm





03.01

12:32

1 = 25MV/CM

200MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 10

$$\tau = 71.2s$$

$$5\tau = 5.9min$$

SAMPLE # 3

MATERIAL:

CAPRAN 512 H

MANUFACTURER:

ALLIED

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

D-257 : $> 2 \times 10^{15} \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 31 %

MEASURED VOLTAGE

(VERT): 250 V/cm

03.01

14:13

1 = 50MV/CM

200MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 11

$\tau = 51 \text{ s}$

$5\tau = 4 \text{ min}, 15 \text{ sec}$

SAMPLE # 7

MATERIAL:

CAPRON 512 H

MANUFACTURER:

ALLIED

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

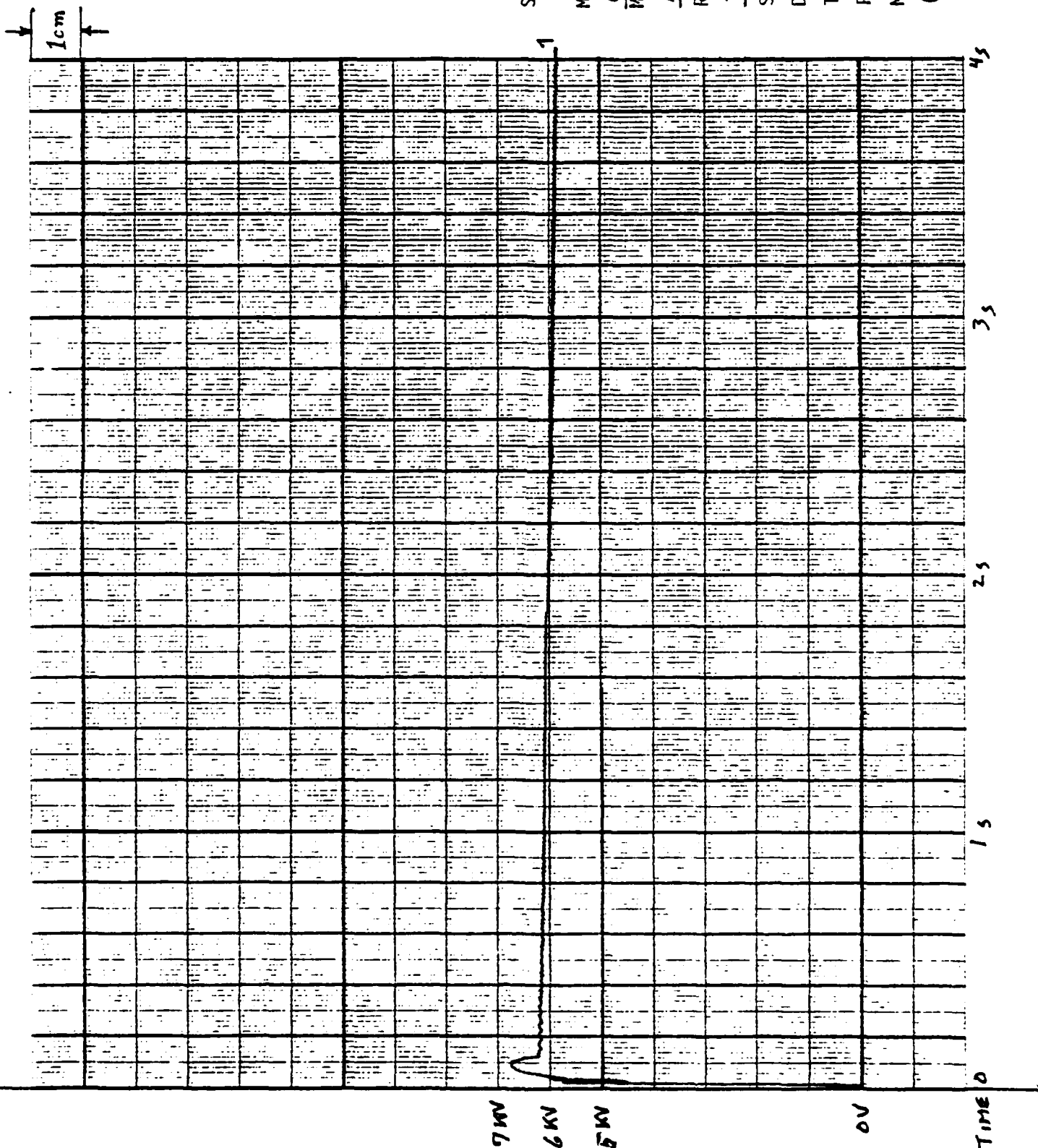
D-257: $> 2 \times 10^{15} \Omega/\square$

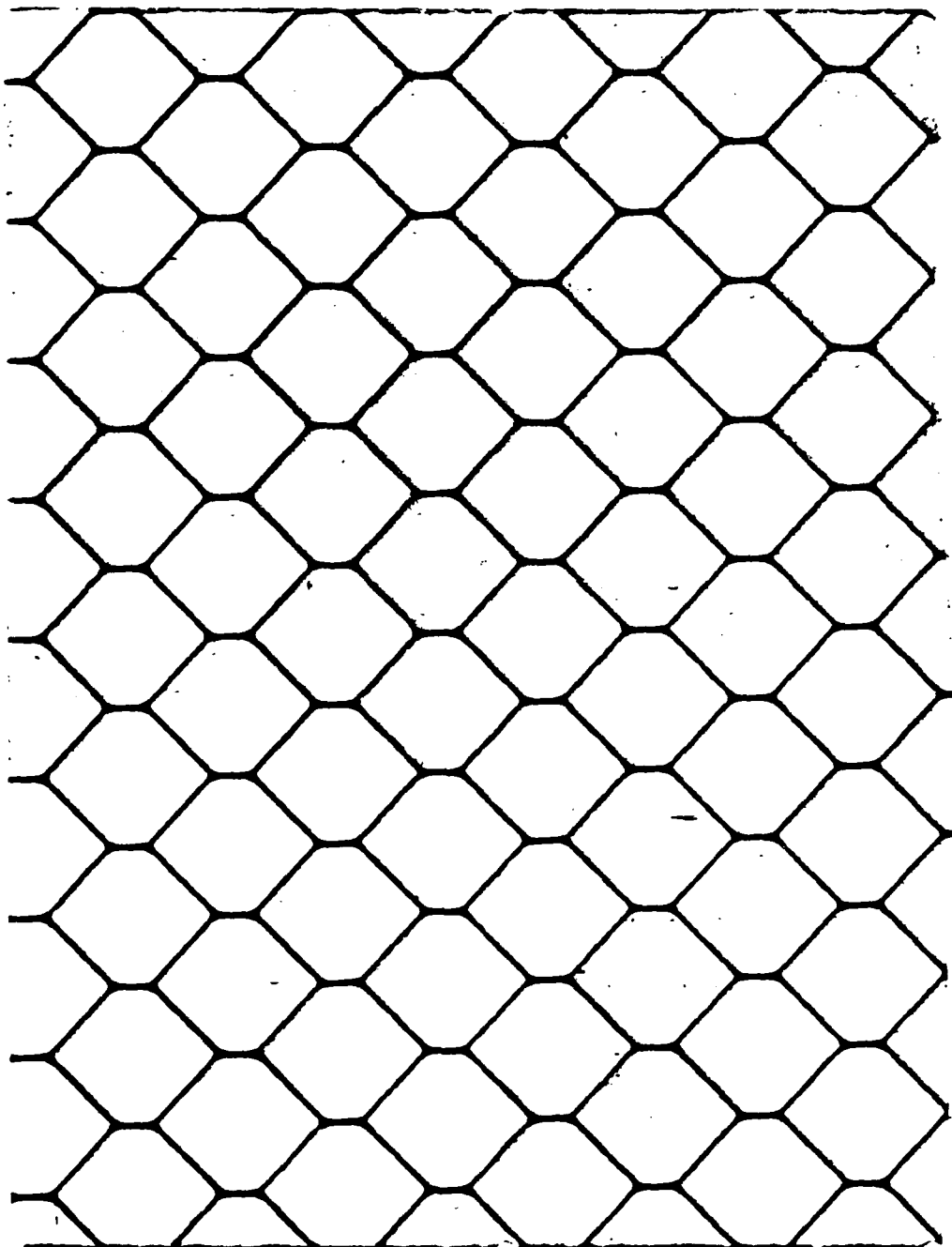
TEMP.: 23 °C

REL. HUM.: 31 %

MEASURED VOLTAGE

(VERT): 1KV/cm





ELECTRO-SAFE

FIGURE 12

03.02

09:21

1 = 50MV/CM

50MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 13

SAMPLE # 3

MATERIAL:

ELECTROSHFE

MANUFACTURER:

WILSON

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

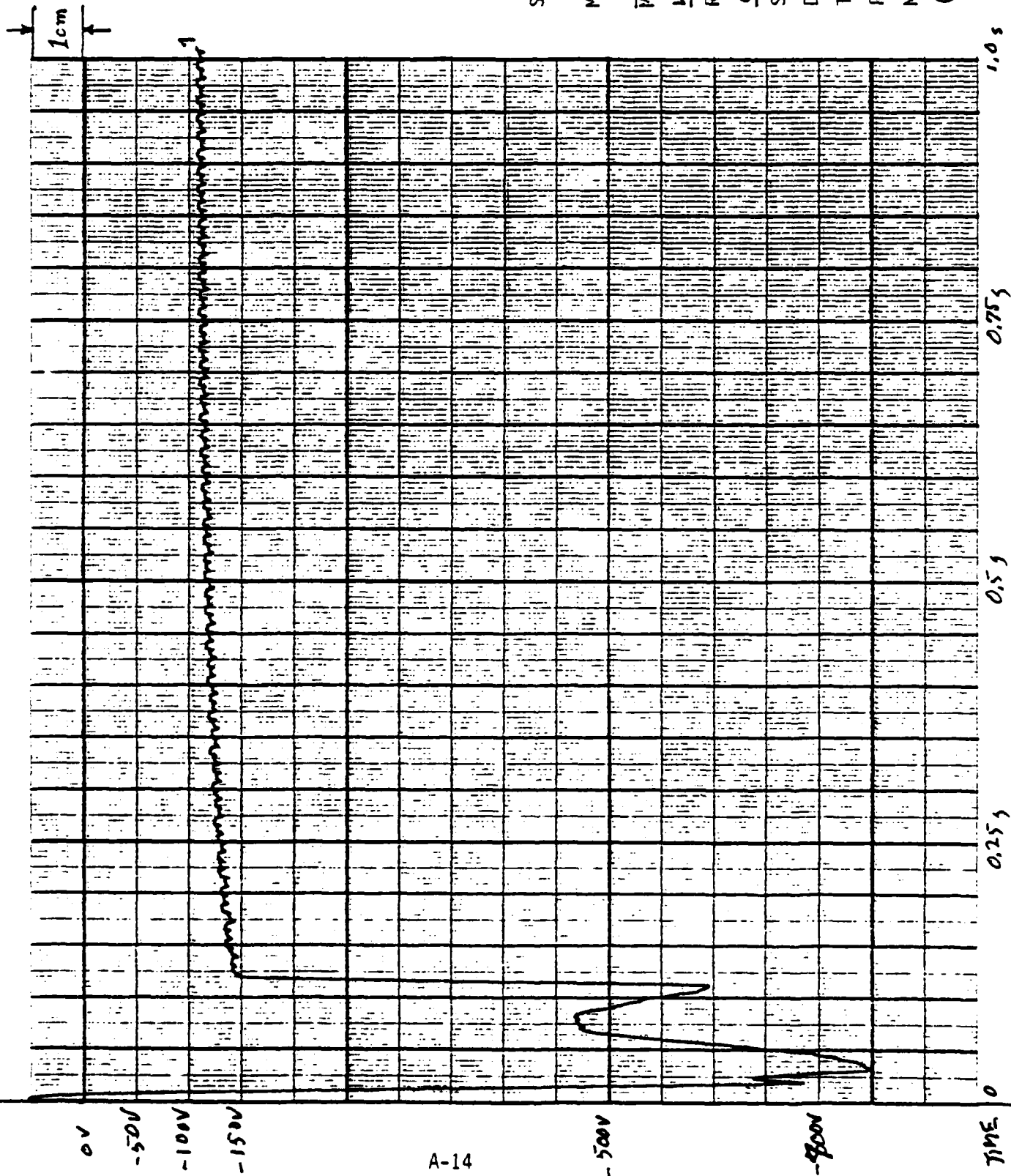
D-257 : $3 \times 10^{14} \Omega/\square$

TEMP.: 22 °C

REL. HUM.: 29.5 %

MEASURED VOLTAGE

(VERT): 50V /cm



03.02

11:15

1 = 0.1 V/CM

50MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 14

$\tau = 0.194 \text{ s}$

$\tau = 0.971 \text{ s}$

SAMPLE # 6

MATERIAL:

ELECTROSAFE

MANUFACTURER:

WILSON

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

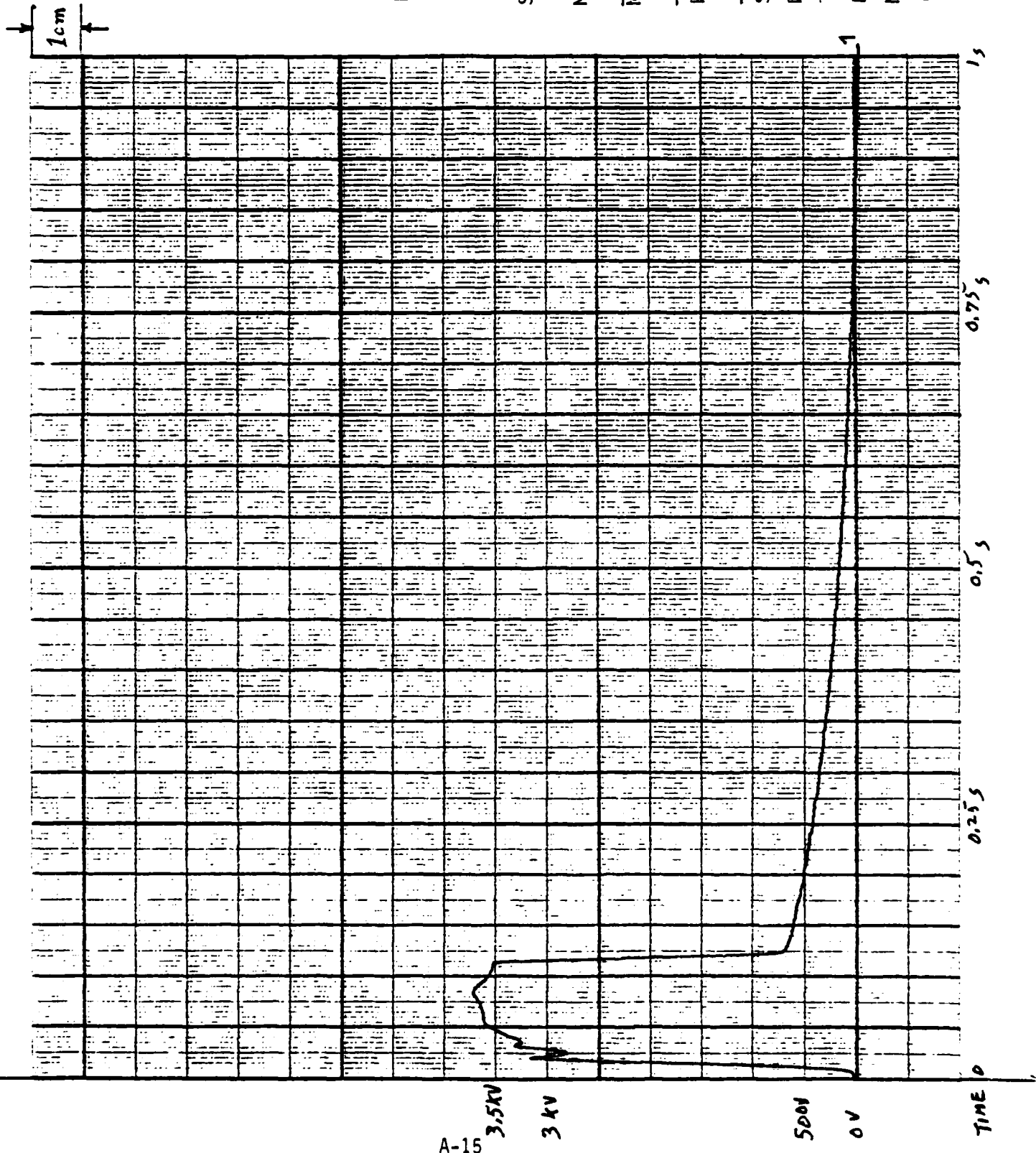
D-257 : $3 \times 10^{14} \Omega/\square$

TEMP.: 22 °C

REL. HUM.: 29.5 %

MEASURED VOLTAGE

(VERT): 500 V /cm



TRG P 0CM

FIGURE 15

$$\chi = 0.113$$
$$57 = 0.5645$$

SAMPLE # 6

MATERIAL:

PRV-1310

MANUFACTURER:

SNYDER

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

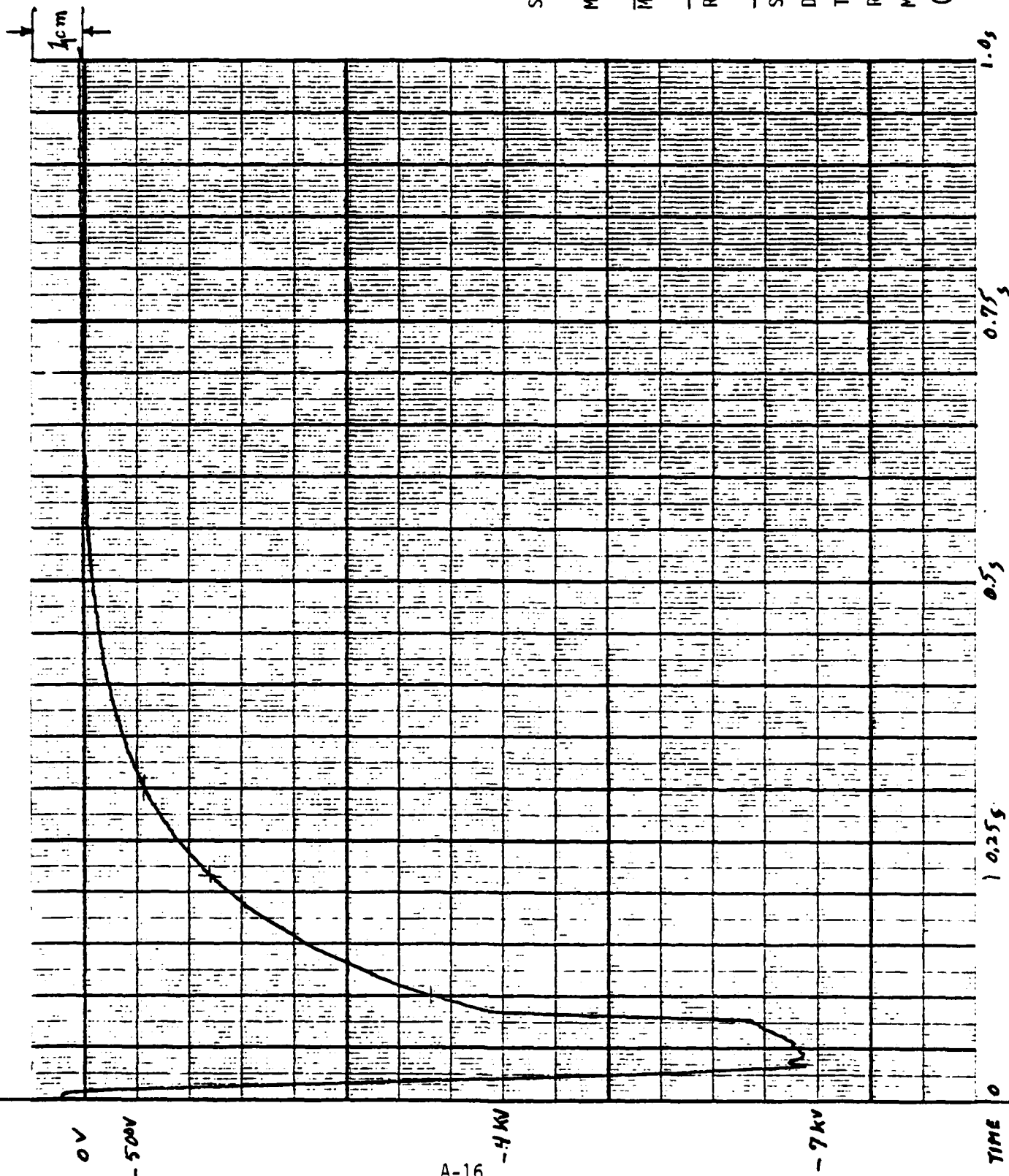
D-257 : $5.5 \times 10^{12} \Omega/\square$

TEMP.: 22 °C

REL. HUM.: 29.5 %

MEASURED VOLTAGE

(VERT): 500V/cm



03.02

15:16

1 = 50MV/CM

50MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 16

$\tau = 0.117 \text{ s}$

$5\tau = 0.586 \text{ s}$

SAMPLE # 2

MATERIAL:

PRV-1310

MANUFACTURER:

SNYDER

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

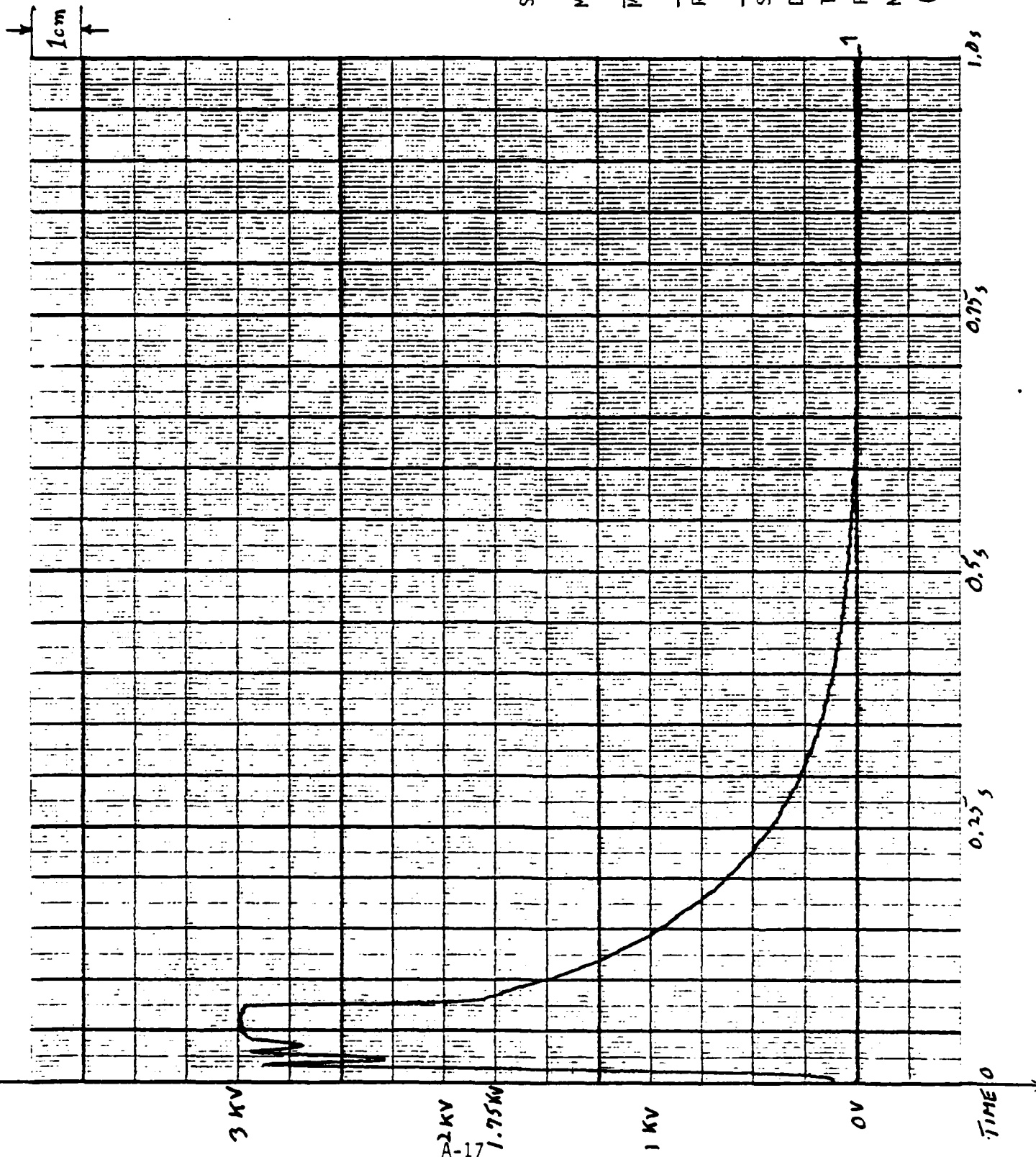
D-257: $5.5 \times 10^{12} \Omega/\square$

TEMP.: 22 °C

REL. HUM.: 29.5%

MEASURED VOLTAGE

(VERT): 250 V/cm



03.02

15:50

1 = 50MV/CM

50MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 17

$\tau = 0.121 \text{ s}$

$5\tau = 0.606 \text{ s}$

SAMPLE # 9

REVERSE SIDE

MATERIAL:

POV-1310

MANUFACTURER:

SNYDER

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

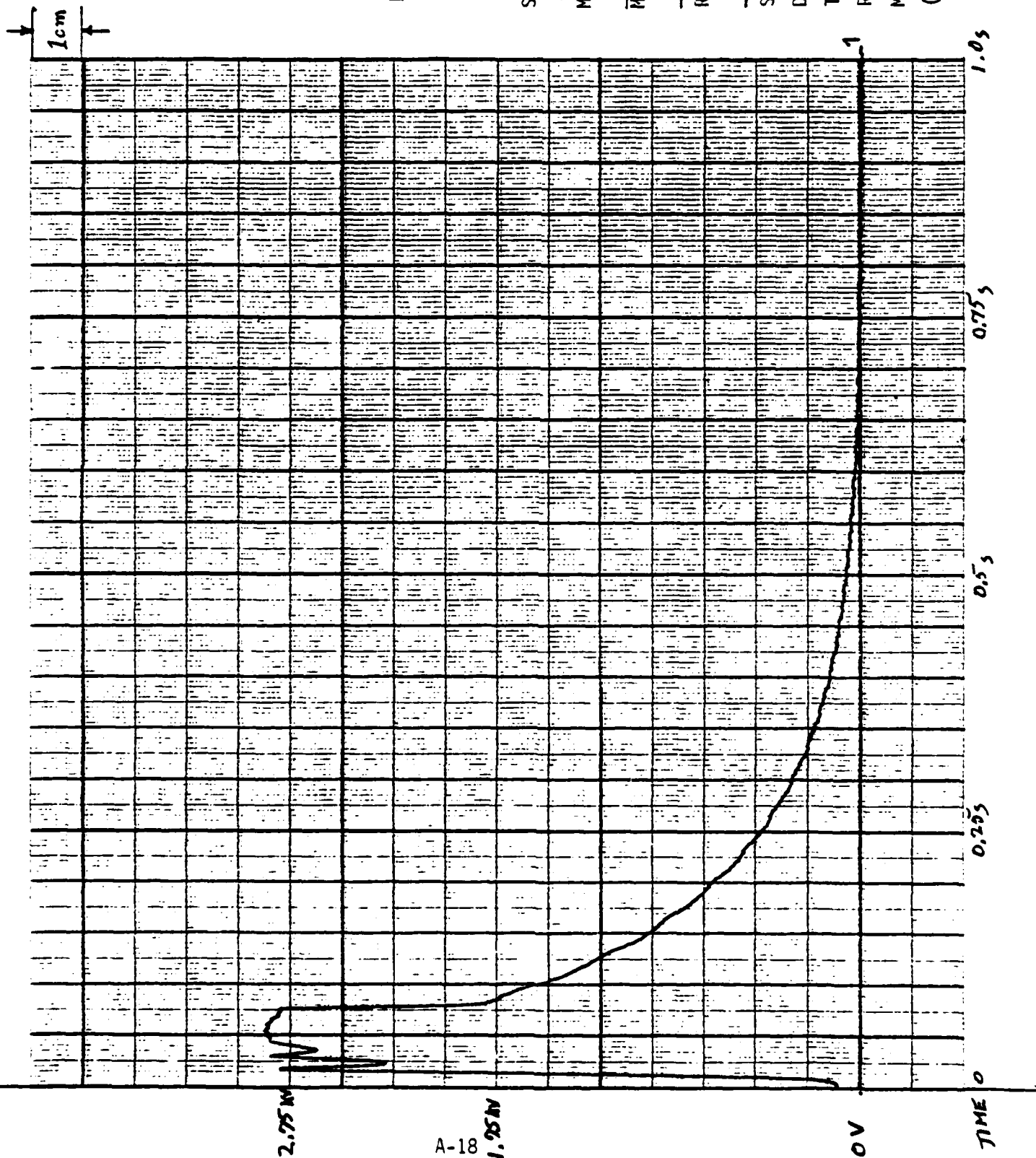
D-257 : $5.5 \times 10^{12} \Omega/\square$

TEMP.: 22 °C

REL. HUM.: 29.5%

MEASURED VOLTAGE

(VERT): 250 V/cm



03.08

09:51

1 = 0.1 V/CM

500MS/CM

50 DATA/CM

TRG 100CM

FIGURE 18

$\tau = 14.2 \text{ s}$

$\delta\tau = 71.1 \text{ s}$

SAMPLE # 5

MATERIAL:

RCAS 2400

MANUFACTURER:

RICHMOND

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

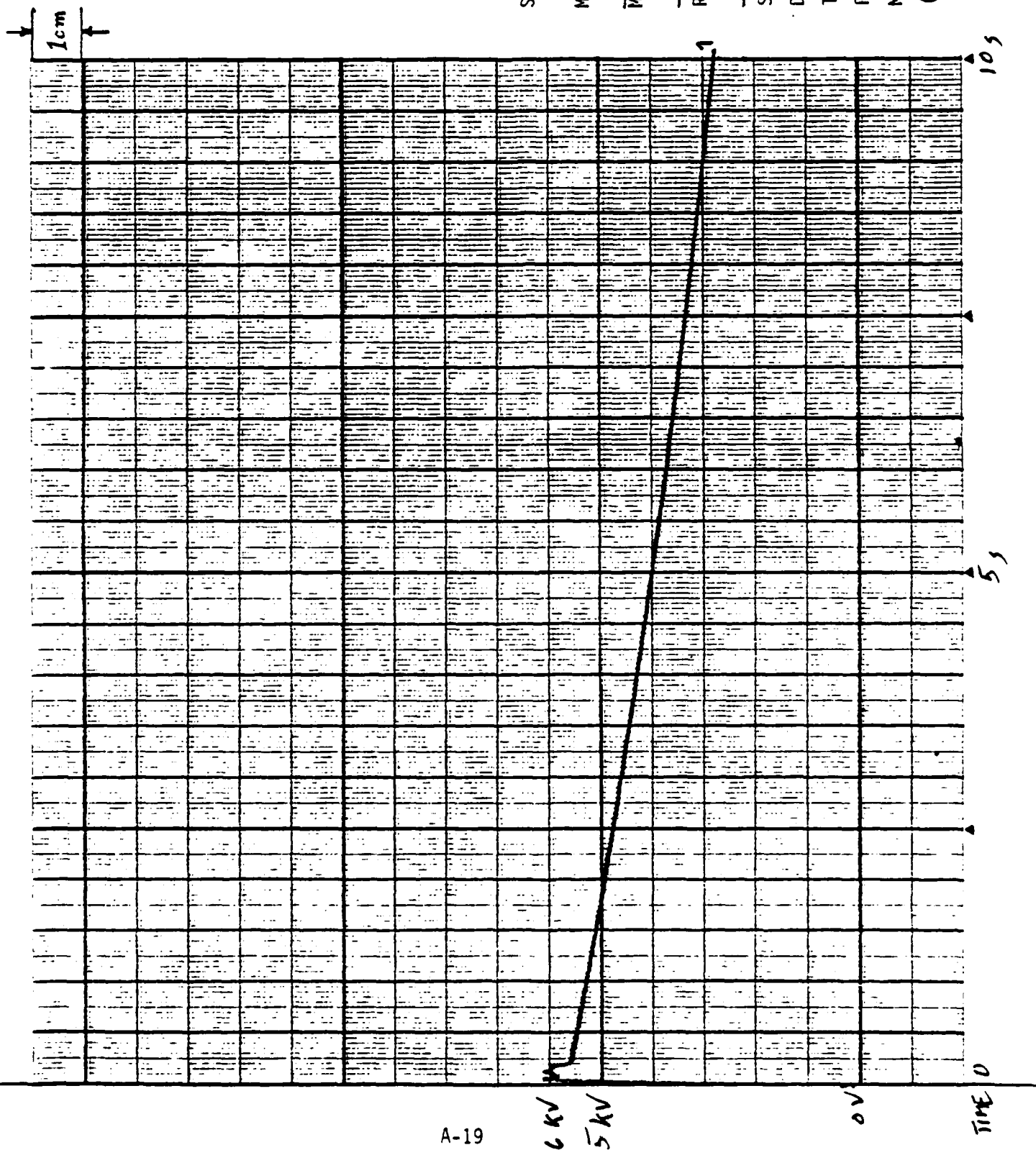
D-257 : $5.5 \times 10^{13} \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 38 %

MEASURED VOLTAGE

(VERT): 1 KV /cm



03.04

16:13

1 = 0.1 V/CM

1S/CM

50 DATA/CM

TRG P 0CM

FIGURE 19

$\tau = 6.78 \text{ s}$

$5\tau = 33.9 \text{ s}$

SAMPLE # 9

MATERIAL:

RCHS-2400

MANUFACTURER:

RICHMOND

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

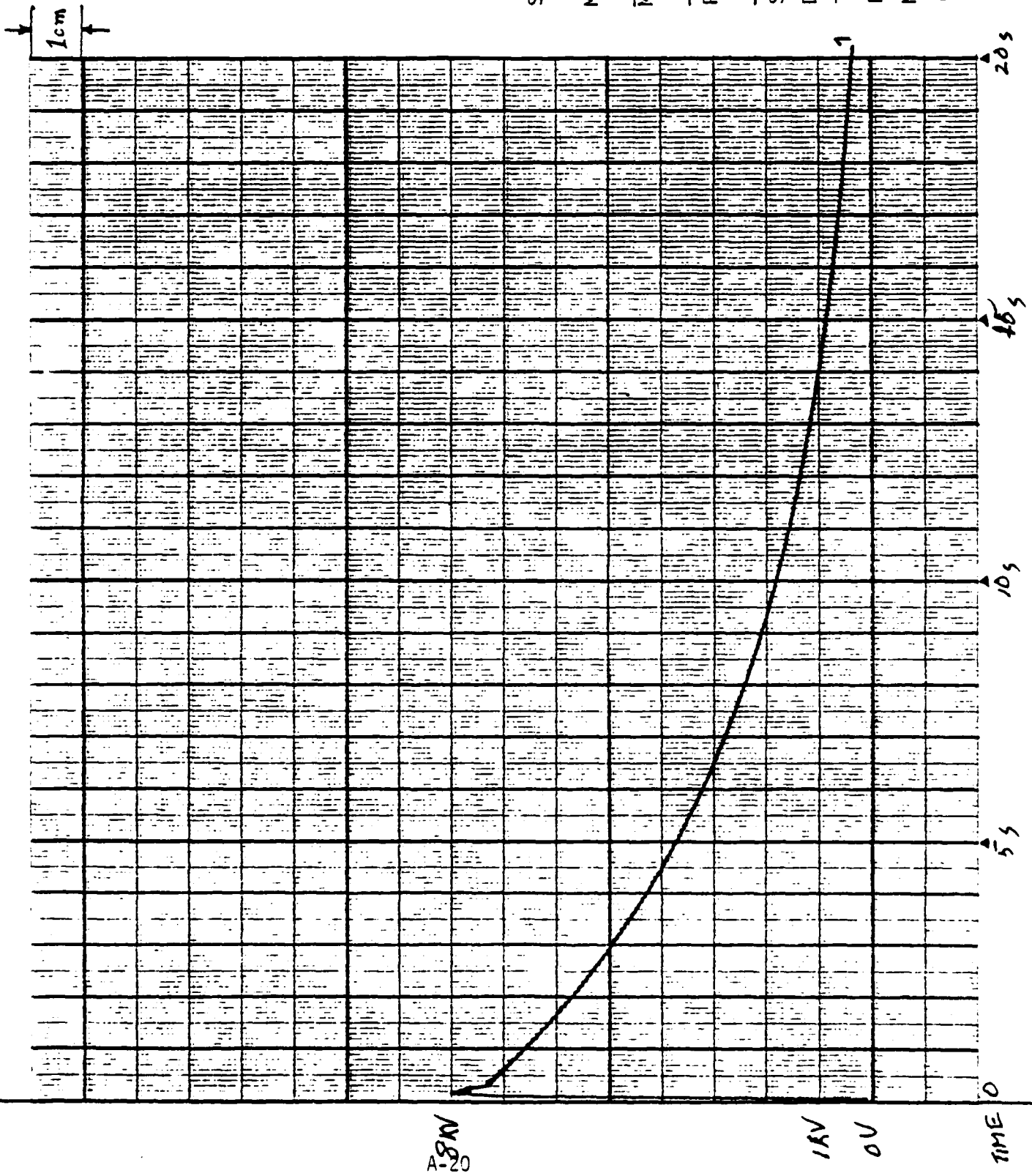
D-257 : $5.5 \times 10^{11} \Omega/\square$

TEMP.: 24 °C

REL. HUM.: 33 %

MEASURED VOLTAGE

(VERT): 1 KV/cm



A-8W
A-20

03.08

11:13

1 = 0.25 V/CM

500MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 20

$\tau = 3.97 \text{ s}$

$5\tau = 19.8 \text{ s}$

SAMPLE # 8

MATERIAL:

RCAS 2400

MANUFACTURER:

RICHMOND

RUBBING MEDIA:

RCAS 2400

SURF. RES. IAW ASTM

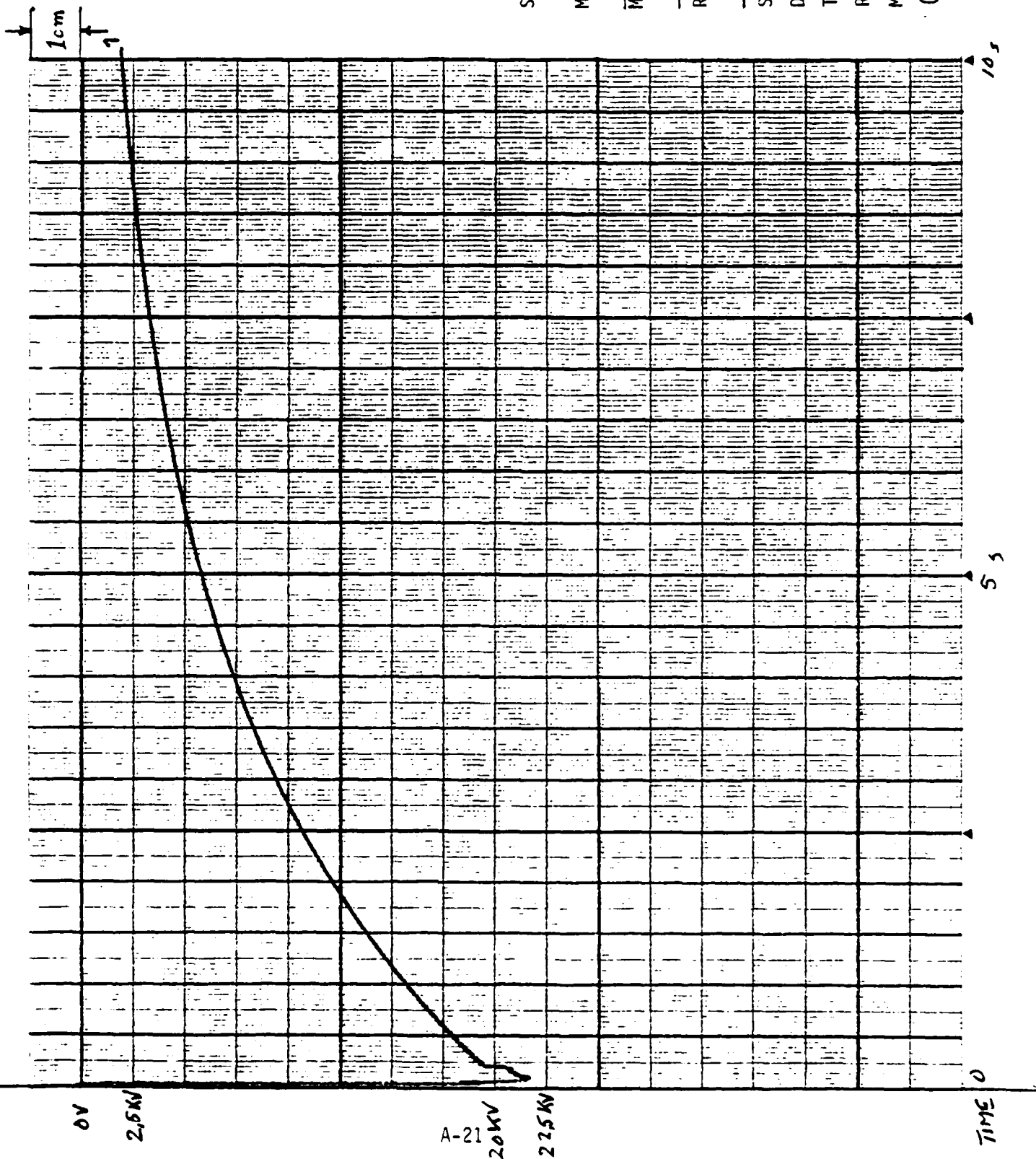
D-257 : $5.6 \times 10^{13} \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 38 %

MEASURED VOLTAGE

(VERT): 2.5 KV/cm



03.11

14:38

1 = 25MV/CM

200MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 21

SAMPLE # 3

MATERIAL:

SARIN 18L

MANUFACTURER:

DOW

RUBBING MEDIA:

CAT FOR

SURF. RES. IAW ASTM

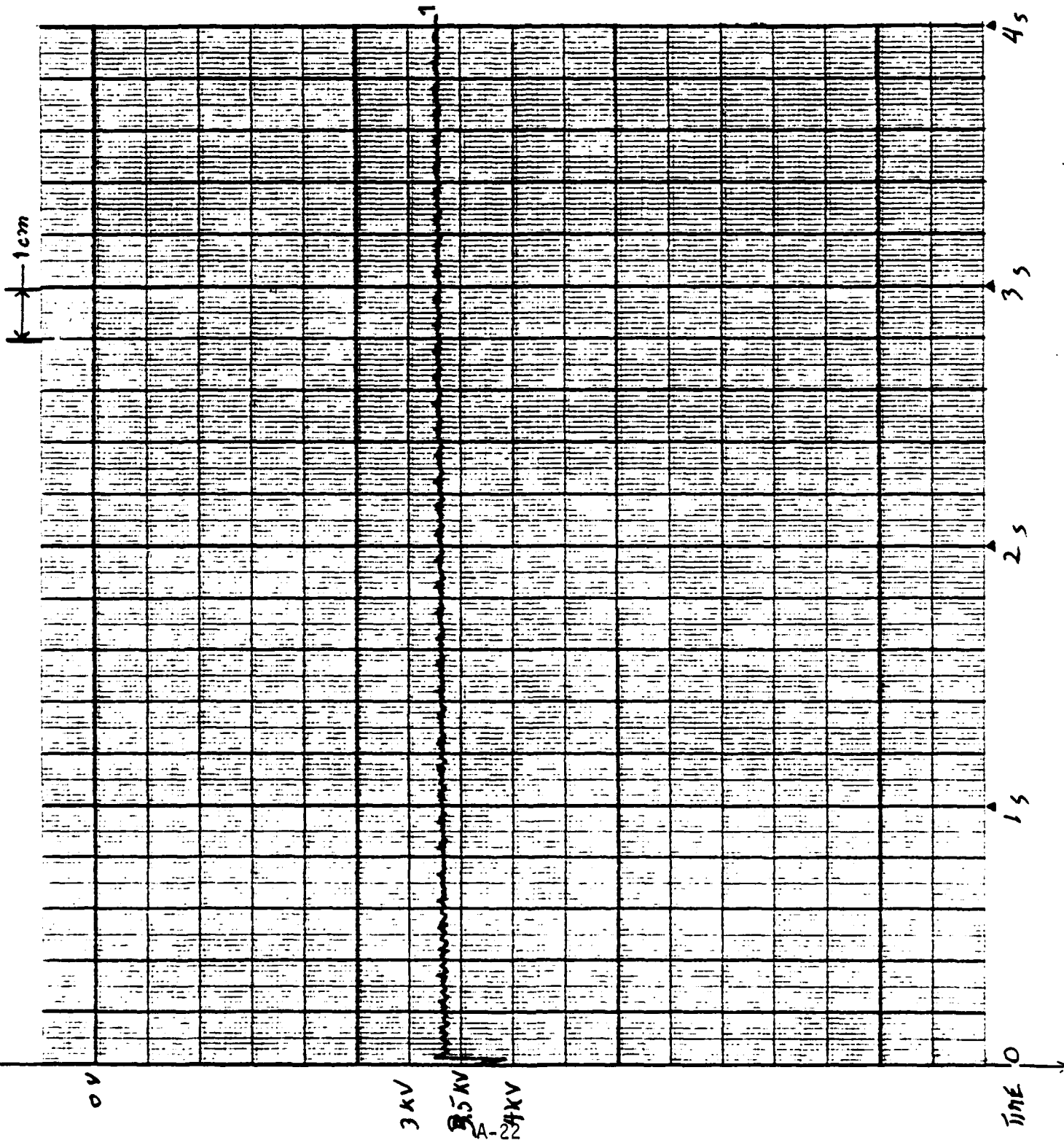
D-257 : $> 2 \times 10^{15} \Omega/\square$

TEMP.: 24 °C

REL. HUM.: 39 %

MEASURED VOLTAGE

(VERT): 500V/cm



03.11

14:57

1 = 50MV/CM

200MS/CM

50 DATA/CM

TRC P 0CM

FIGURE 22

SAMPLE # 1

MATERIAL:

SARAN 18 L

MANUFACTURER:

DOW

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

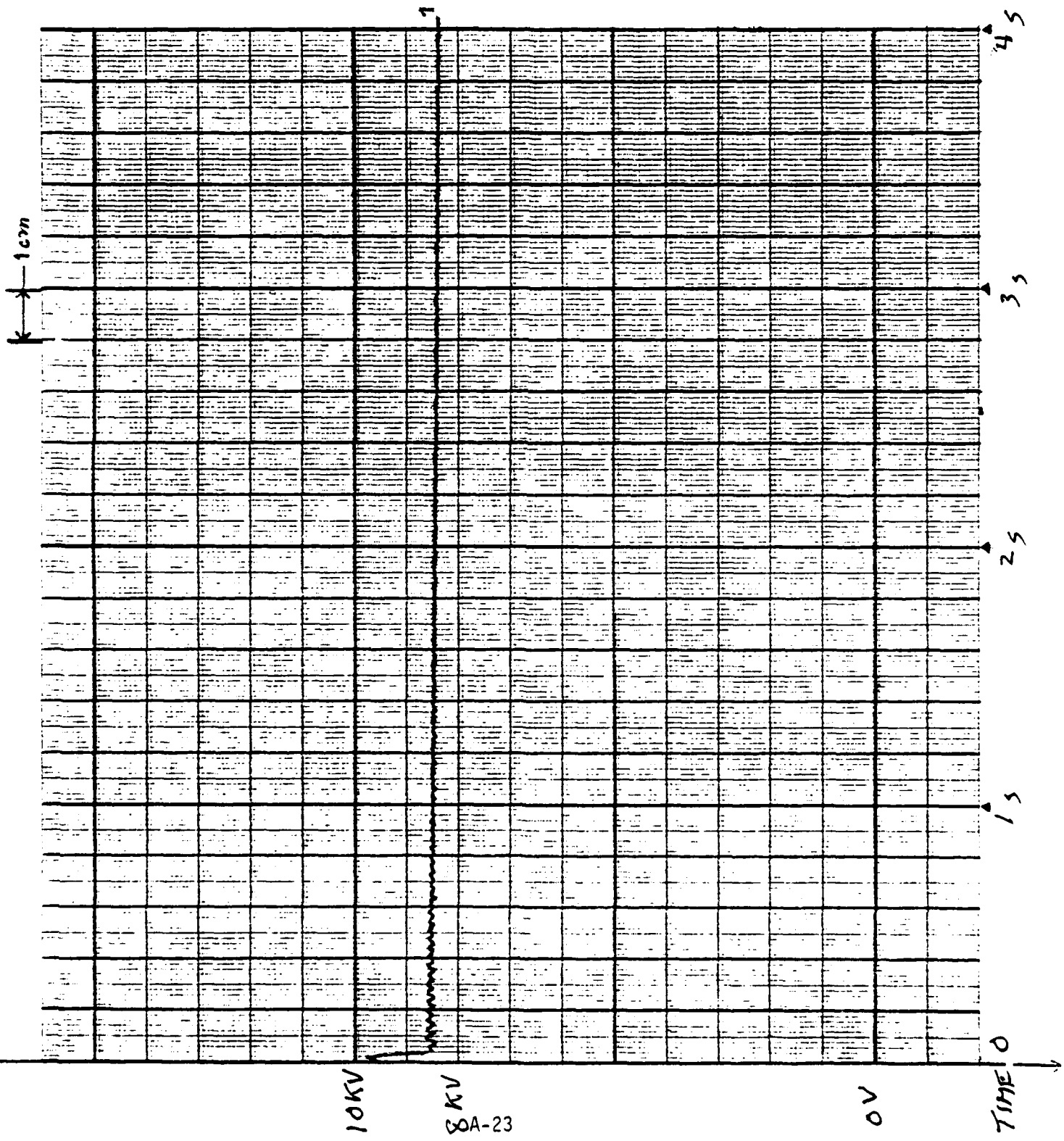
D-257 : $>2 \times 10^{13} \Omega/\square$

TEMP.: 24 °C

REL. HUM.: 39 %

MEASURED VOLTAGE

(VERT): 1 KV /cm



03.09

15:03

1 = 50MV/CM

5MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 23

$\tau = 0.0045 \text{ s}$

$5\tau = 0.0225 \text{ s}$

SAMPLE # C

MATERIAL:

AS 1400

MANUFACTURER:

WRIGHTLON

RUBBING MEDIA:

CAT FUR

SURF. RES. IAW ASTM

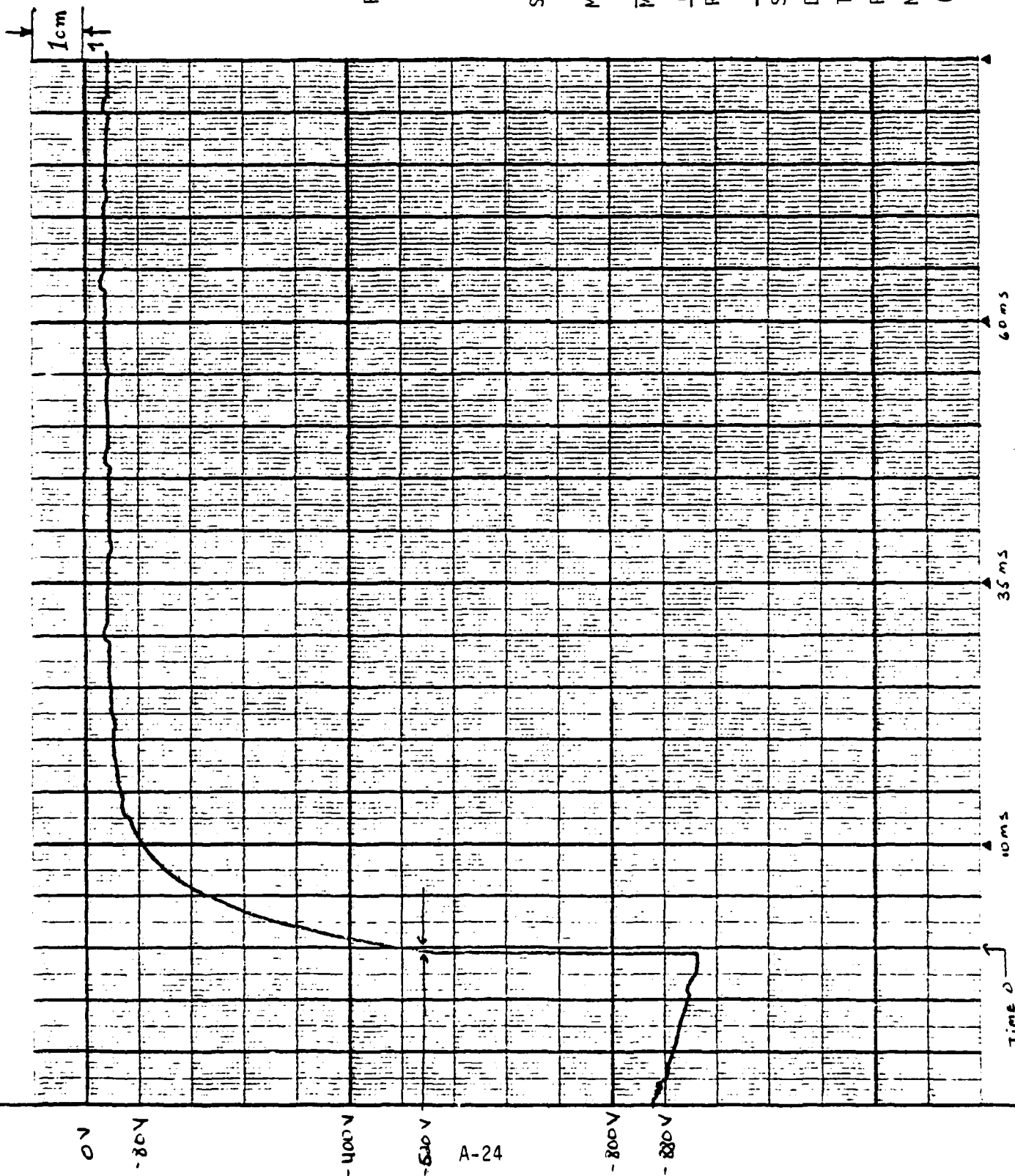
D-257: $5 \times 10^9 \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 38 %

MEASURED VOLTAGE

(VERT): 80 V/cm



03.10

10:22

1 = 50MV/CM

5MS/CM

50 DATA/CM

TRG P 0CM

FIGURE 24

$$\tau = 0.0046 \text{ s}$$

$$5\tau = 0.0228 \text{ s}$$

SAMPLE # 6

MATERIAL:

AS 1400

MANUFACTURER:

WRIGHT LON

RUBBING MEDIA:

TEFLON

SURF. RES. IAW ASTM

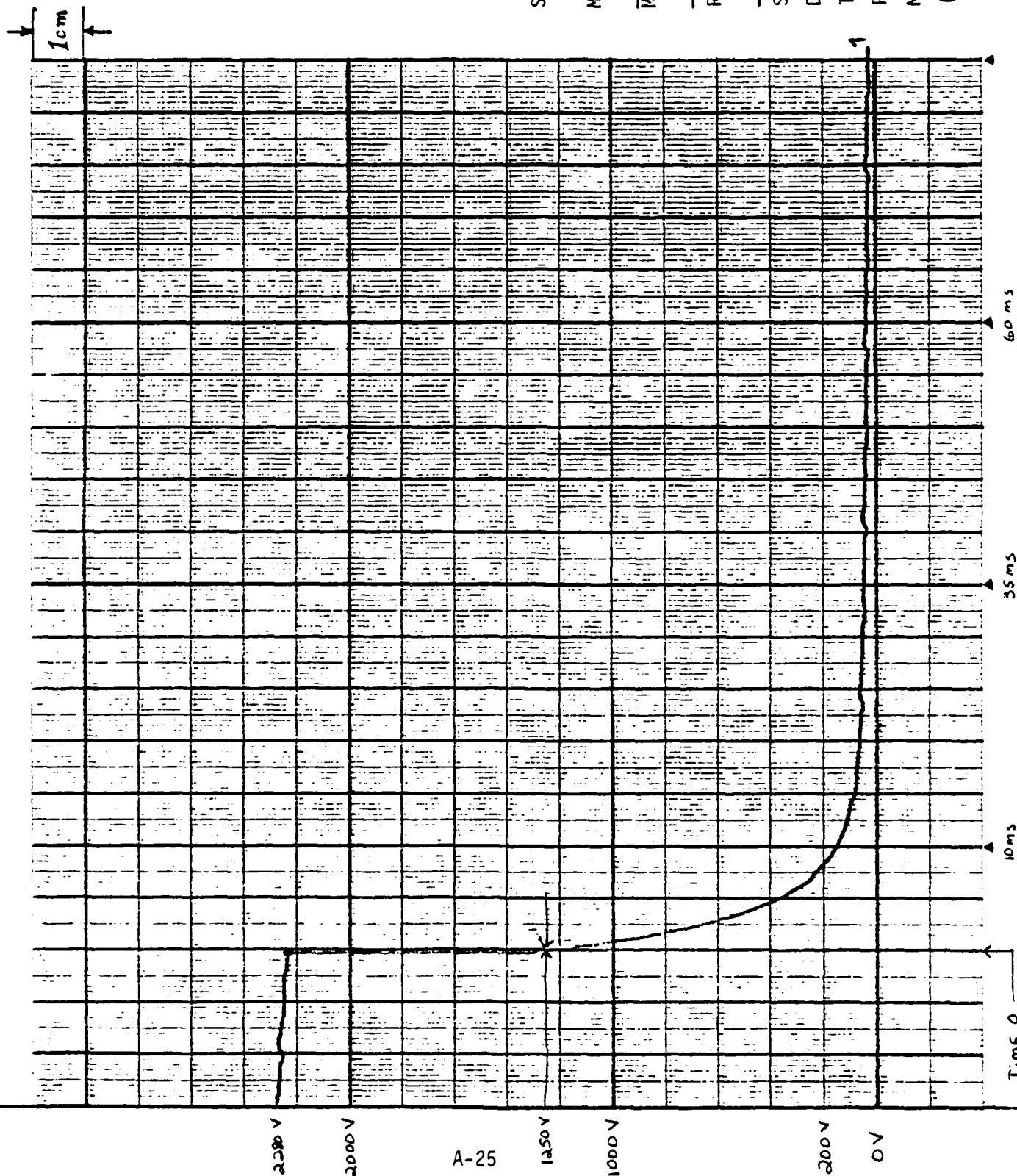
D-257 : $5 \times 10^{11} \Omega/\square$

TEMP.: 23 °C

REL. HUM.: 40 %

MEASURED VOLTAGE

(VERT): 200 V/cm



APPENDIX B
KENNEDY SPACE CENTER DOCUMENTS

TRIBOELECTRIC TEST FOR THE
LABORATORY EVALUATION
OF
ELECTROSTATIC DECAY

KENNEDY SPACE CENTER

3 APPLICABLE DOCUMENTS

3.1 ASTM Standards:

E 104 Maintaining Constant Relative Humidity by means of Aqueous Solutions.

4 SUMMARY OF METHOD

4.1 Specimens cut from the protective clothing are preconditioned to the required humidity for 24 hours prior to testing. The test specimen is then mounted in the specimen holder, a static charge is generated by rubbing with a polytetrafluoroethylene (PTFE) coated wheel for 10 seconds, and the charge generated and decay rate is followed using a storage oscilloscope¹ (NOTE 1).

NOTE 1 Other recording methods are acceptable, but error may result in cases of rapid charge decay.

5 APPARATUS AND MATERIALS

5.1 The Triboelectric tests are performed with the apparatus shown in Figure 1. The apparatus consists of a bonded aluminum frame properly earth grounded (maximum resistance to be less than 5 ohms, see NEC) on which are mounted a PTFE rubbing disc driven by 1/50 hp electric motor, the sample holder, and the static voltage detection

¹A Tektronix Model 549 Storage Oscilloscope has been found to be satisfactory.

head.² The motor drive and PTFE wheel are mounted on a sliding carriage which can be moved forward or retracted by a control lever. The PTFE rubbing disc, which is 12.5 cms in diameter and is machined with a convex surface of approximately 12-inches radius, is cemented to a Micarta® support fitted with a 1/4-inch diameter aluminum shaft that is clamped in a chuck on the disc drive shaft. This shaft is belt driven by the motor through pulleys such that the disc speed is 400 ± 20 rpm.

5.2 For testing fluorocarbon materials, an alternate rubbing disc, such as untreated wool, is required.

5.3 Desiccator, 250 mm diameter.

5.4 Salts and solutions for the desired humidity as specified in ASTM E 104.

6 SAMPLING

6.1 Five specimens, each measuring 17 by 19 cms shall be selected for each test.

6.2 Specimens from garments should include all of the layers held in the relative position they occupy in the garment.

7 PREPARATION OF TEST SPECIMENS

7.1 Five specimens, each 17 by 19 cms, shall be marked out on the surface opposite that to be tested. The

2A Keithley Model 2501 Static Voltage Detection Head coupled with a Keithley Model 610C Electrometer has been found to be satisfactory for this purpose.

specimens shall then be cut from the garment or materials of construction.

7.2 The test specimens shall be conditioned at the desired relative humidity for 24 hours before testing. This conditioning may be performed in a humidity cabinet or in a desiccator above a suitable solution (ASTM E 104) which provides the required humidity (relative humidities of 35, 50, and 65% are suggested).

7.3 One specimen at a time is removed from the controlled environment and tested within five minutes of removal.

8 PROCEDURES

8.1 Place the test sample in the hinged sample holder, which is provided with parallel ridges and matching grooves on the sides, to stretch the sample as the clamping nuts are tightened. With the test sample in place, raise the sample holder in front of the PTFE disc, and move the disc control lever to lock the sample holder in place with the positioning pin. Reset the measuring and recording equipment and move the PTFE disc forward against the stop which allows it to contact the test sample and assures that it is in the same plane for each sample.

8.2 Using the carriage lever, retract the rubbing disc from the test sample after 10 seconds. This action actuates a microswitch, which triggers the storage oscilloscope, and permits the sample holder to swing through an arc of approximately 90 degrees and to lock into position in front of the static detection head. This detector is connected to the electrometer, the output circuit of which is connected to the vertical deflection input terminals of a differential amplifier plug-in module in

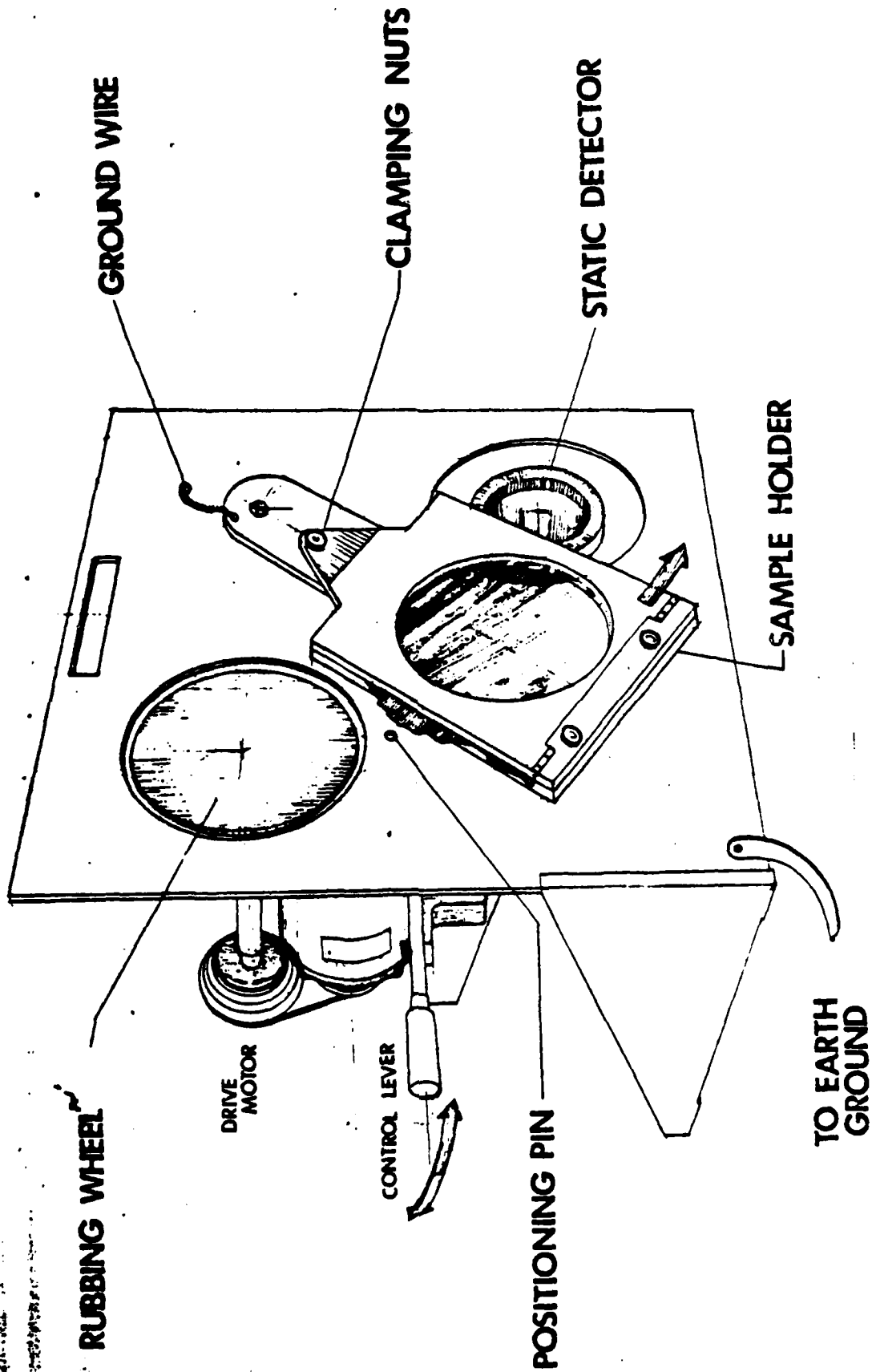
the storage oscilloscope (or alternative recording device if desired). Points on the resultant oscilloscope trace are related to the expired time interval beginning at cessation of rubbing (which is initiation of charge dissipation). The time interval between cessation of rubbing and initial oscilloscope pick-up of the discharge curve is 0.35 ± 0.02 second, which is the time required for free fall of the sample holder to the detector head. The horizontal (time) scale on the oscilloscope can be adjusted to a relatively short or long time span. The usual time span used for electrostatic tests on plastic films or garment materials is 5 seconds.

9 REPORT

- 9.1 The temperature and relative humidity at which the test specimens are conditioned shall be recorded.
- 9.2 The initial charge generated on each test specimen shall be recorded and may be averaged if desired. If the results are averaged, the highest and lowest values shall also be reported.
- 9.3 The decay of the static charge may be read directly from the oscilloscope screen at 1 second intervals and recorded. Other time intervals may be chosen if desired, but must be so stated.

10 SUGGESTED INTERPRETATION OF RESULTS

- 10.1 The static charge and decay properties of a material should be measured at several relative humidities to provide information for the ranking of materials.



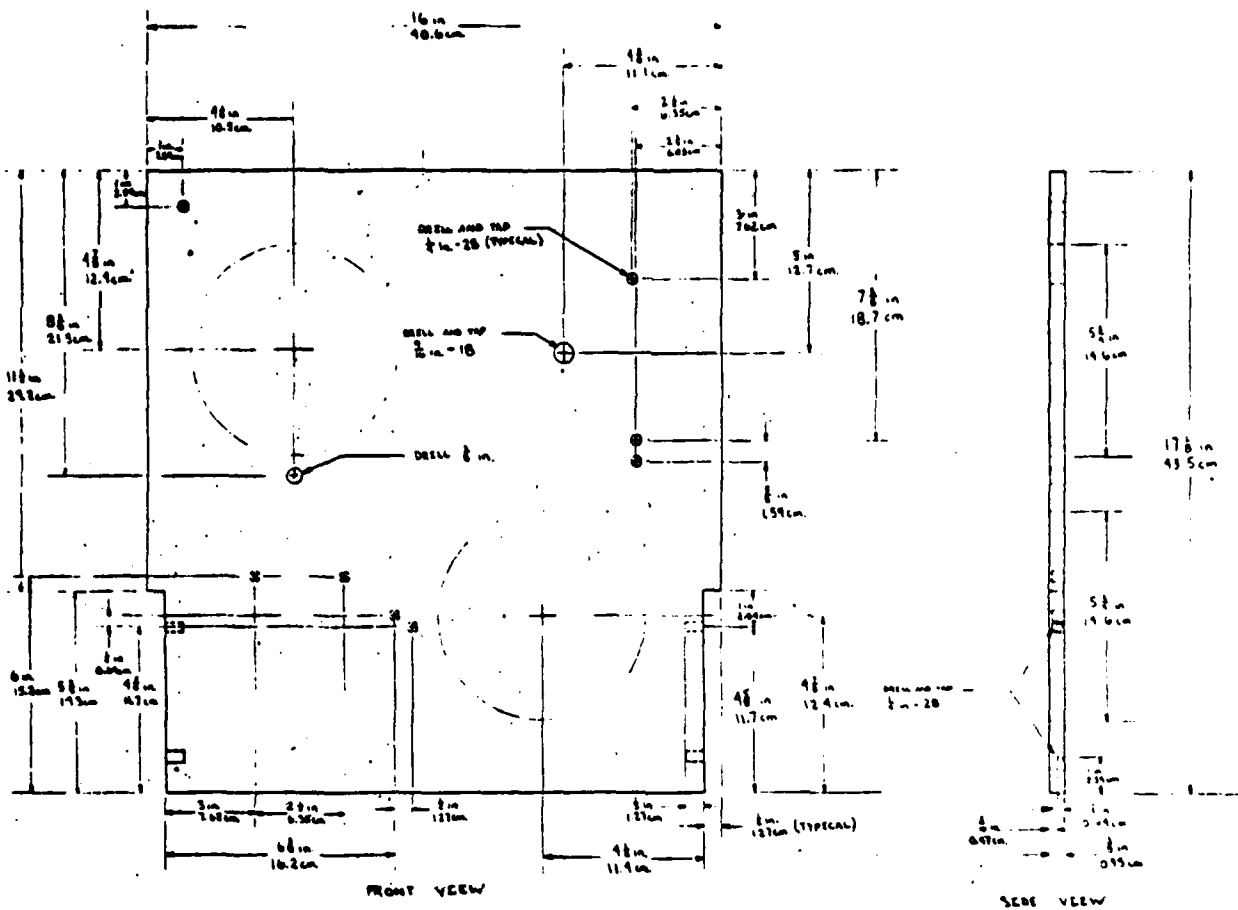


FIG. 2 Test Panel

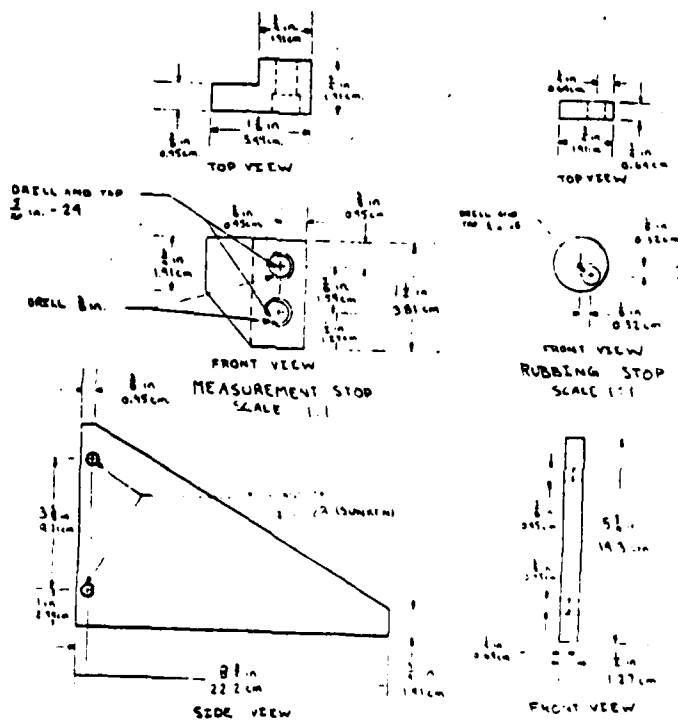


FIG. 3 Test Panel Support
(2 required)

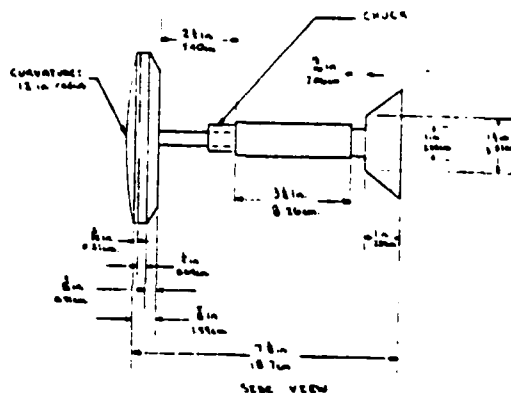
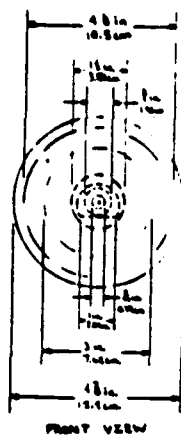


FIG. 4 Rubbing Wheel

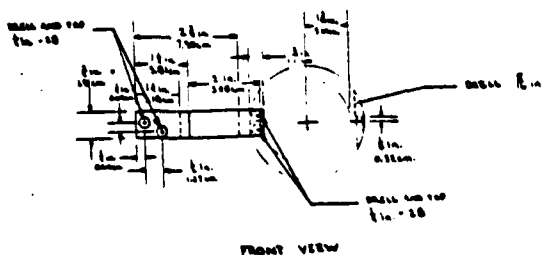
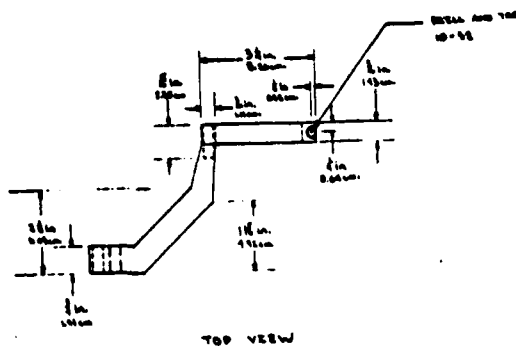


FIG. 5 Static Detector Bracket

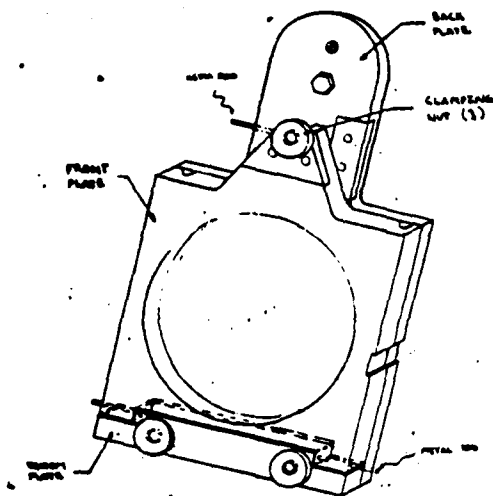


FIG. 9 Sample Holder

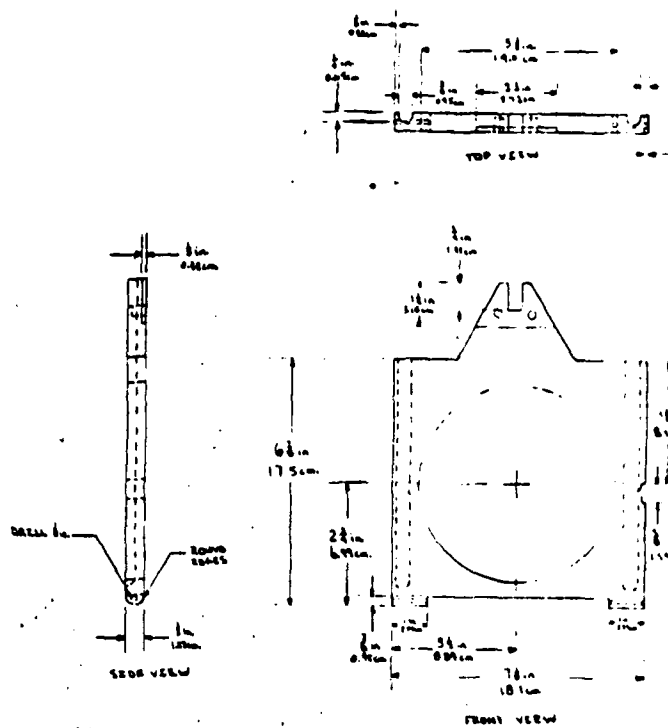


FIG. 10 Sample Holder Front Plate

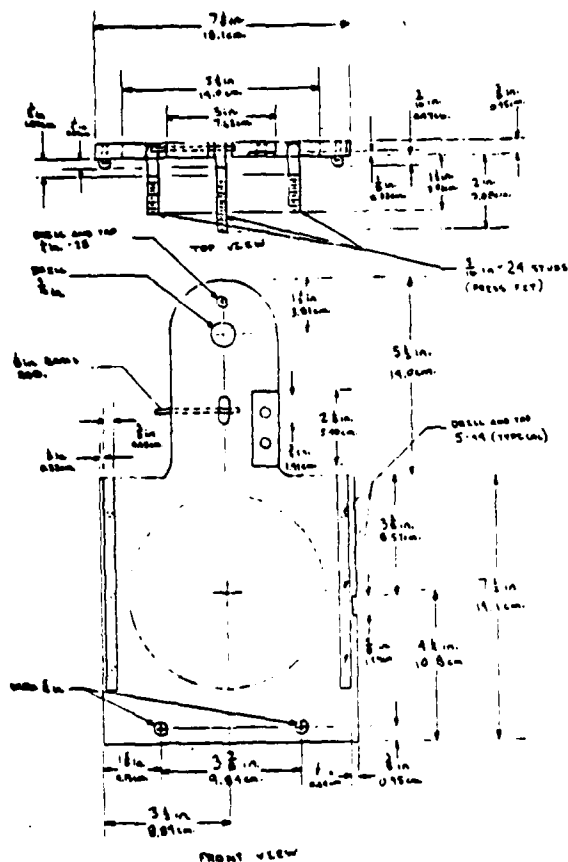


FIG. 11 Sample Holder Back Plate

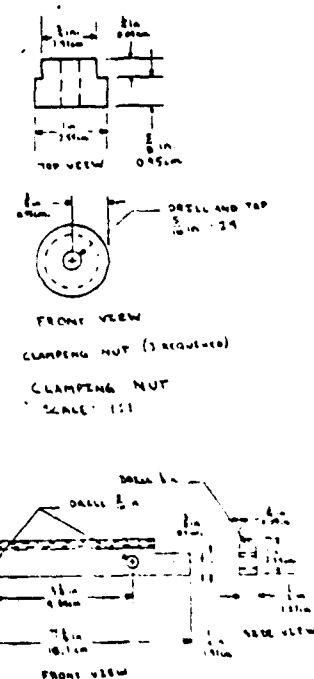


FIG. 12 Sample Holder Bottom Plate

NASA
MATERIALS TESTING SECTION
MATERIALS ANALYSIS BRANCH
FLUIDS AND ANALYSIS DIVISION
TG-FLD-22, ROOM 1218, O&C BUILDING
KENNEDY SPACE CENTER, FLORIDA 32899
APRIL 15, 1981

MMA-2116-80

SUBJECT: Physical Characteristics of Twelve Materials

1.0 FOREWORD

1.1 On October 31, 1980, twelve materials were submitted to the MMA laboratory by Mr. J. A. Aliberti, NASA, SF-ENG, for an evaluation of their physical properties.

1.2 The twelve materials were identified as follows:

1.2.1 Aclar, a clear, unplasticized, non surface treated polychlorotrifluoroethylene manufactured by the Allied Chemical Company.

1.2.2 Capran 80, a clear nylon 6 manufactured by the Allied Chemical Company.

1.2.3 Capran 512H (512 HLT and 512 HLTX), a clear transparent, nylon 6 manufactured by the Allied Chemical Company.

1.2.4 Electro-safe, a clear (with grid) PVC vinyl, manufactured by the Wilson Sales Company.

1.2.5 Lectrolite, a black/navy material manufactured by Herculite Products, Incorporated.

- 1.2.6 PRV-1310, a green woven polyester material laminated between vinyl film layers, manufactured by the Snyder Manufacturing Company of Dover, Ohio.
- 1.2.7 RCAS-2400, a transparent (with orange tint) heat stabilized nylon material manufactured by the Richmond Corporation.
- 1.2.8 Saran 18L, a clear (light tan tint) polyvinylidene chloride manufactured by the Dow Chemical Company.
- 1.2.9 Velostat Film, a black, carbon impregnated polyethylene vinyl acetate material manufactured by the 3M Company.
- 1.2.10 Wrightlon AS-1400, a light pink transparent material manufactured by the International Plastic Products, Incorporated.

2.0 TEST PROCEDURES

2.1 Electrostatic Properties

After being conditioned to the laboratory environment for at least 24 hours, the following triboelectric test was performed. Each specimen, after being rubbed with a Teflon-coated wheel for 10 seconds to produce a static charge, was quickly positioned in front of the detecting head of an electrometer. The recorder output from the electrometer was connected to the input of a storage oscilloscope. A charge-vs-time plot of the charge dissipation properties for each test item was presented on the oscilloscope screen.

2.2 This test was performed on each material at relative humidities of 59%, 46%, 37%, and 18%. The samples were then exposed on the beach for three weeks to determine the effect of ultraviolet radiation on their electrostatic properties and retested (Table 5) at 42% relative humidity.

2.3 Flammability Characteristics

The materials were tested for flammability in accordance with Test No. 1, upward propagation test of NHB 8060.1A, "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion." This document states, with regard to criteria of acceptability, as follows:

2.3.1 Material shall be classified as Group I if determined noncombustible, or self-extinguishing before 6 inches of the samples are consumed, the time of burning not to exceed 10 minutes. There shall be no sparking, sputtering, or dripping of flaming particles from the test sample. The sample shall be hung vertically in the test chamber and the igniter placed at the bottom of the sample for a period of 20 seconds.

2.4 Propellant Compatibility

Test specimens--approximately 1-inch square--were cut, placed on watch glasses, and 2 drops of the appropriate test fluids placed on one corner of the specimens. The test fluids consisted of the following: monomethyl

hydrazine, nitric acid, nitrogen tetroxide, and 90% hydrogen peroxide. The specimens were observed for 5 minutes in this configuration to determine if any deleterious effect occurred from exposure to these hypergolic fluids.

3.0 TEST RESULTS

- 3.1 The results of the electrostatic tests are shown in Tables 1 through 5.
- 3.2 The results of the flammability tests are shown in Table 6.
- 3.3 Results of the hypergolic compatibility tests are shown in Table 7.

INVESTIGATORS:

C. G. Bryan
C. G. BRYAN

B. J. Lockhart
B. J. LOCKHART

J. E. Minster
J. E. MINSTER

W. J. Brown
W. J. BROWN

APPROVED:

C. L. Springfield
C. L. SPRINGFIELD, CHIEF, MTS, NASA

TABLE 1
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

		TEMPERATURE: 72°F	RELATIVE HUMIDITY: 59%					
		VOLTAGE DISCHARGE RATE*						
<u>MATERIAL</u>		<u>0.35 SEC</u>	<u>0.5 SEC</u>	<u>1.0 SEC</u>	<u>2.0 SEC</u>	<u>3.0 SEC</u>	<u>4.0 SEC</u>	<u>5.0 SEC</u>
<u>ACLAR</u>								
SAMPLE NO. 1		-4,200	-4,000					
SAMPLE NO. 2		-3,800	-3,600					
SAMPLE NO. 3		-4,800	-4,600					
<u>CAPRAN 80</u>								
SAMPLE NO. 1		12,600	10,200	5,000	1,000	400	200	LESS THAN 100
SAMPLE NO. 2		10,000	8,800	5,400	2,200	800	400	200
SAMPLE NO. 3		12,000	12,000	5,800	1,200	400	LESS THAN 100	—
<u>CAPRAN 512H</u>								
SAMPLE NO. 1		300	LESS THAN 100					
SAMPLE NO. 2		300	LESS THAN 100					
SAMPLE NO. 3		300	LESS THAN 100					
<u>ELECTRO-SAFE</u>								
SAMPLE NO. 1		150	100	LESS THAN 100				
SAMPLE NO. 2		150	100	LESS THAN 100				
SAMPLE NO. 3		150	100	LESS THAN 100				

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 1 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 72°F		RELATIVE HUMIDITY: 59%						
MATERIAL		VOLTAGE DISCHARGE RATE*						
		0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC
<u>LECTROLITE</u>								
SAMPLE NO. 1		LESS THAN 100						
SAMPLE NO. 2		LESS THAN 100						
SAMPLE NO. 3		LESS THAN 100						
<u>PRV-1310</u>								
SAMPLE NO. 1		3,700	1,800	400	200	100	LESS THAN 100	
SAMPLE NO. 2		3,100	1,200	400	200	100	LESS THAN 100	
SAMPLE NO. 3		3,700	1,700	500	200	100	LESS THAN 100	
<u>RCAS 2400</u>								
SAMPLE NO. 1		13,500	10,000	5,000	1,500	500	LESS THAN 100	
SAMPLE NO. 2		13,000	9,500	5,000	1,500	500	LESS THAN 100	
SAMPLE NO. 3		13,000	9,000	3,500	1,000	500	LESS THAN 100	
<u>SARAN 18L</u>								
SAMPLE NO. 1		2,100	1,700					
SAMPLE NO. 2		1,500	1,150	1,100	1,100	1,050		
SAMPLE NO. 3		2,000	1,550	1,500				
<u>VELOSTAT FILM</u>								
SAMPLE NO. 1		LESS THAN 100						
SAMPLE NO. 2		LESS THAN 100						
SAMPLE NO. 3		LESS THAN 100						

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

MMA-2116-80

7

TABLE 1 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 72°F RELATIVE HUMIDITY: 59%

VOLTAGE DISCHARGE RATE*

	0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC
WRIGHTLON AS-1400							
SAMPLE NO. 1	21,000	15,500	8,000	4,000	3,000	2,000	1,500
SAMPLE NO. 2	17,000	14,000	7,500	3,500	2,000	1,500	1,000
SAMPLE NO. 3	20,000	17,500	12,500	8,500	6,000	4,000	3,000

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 2
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

		TEMPERATURE: 71°F		RELATIVE HUMIDITY: 46%					
		VOLTAGE DISCHARGE RATE*							
MATERIAL		0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC	
ACIAR									
SAMPLE NO. 1		-1,500							
SAMPLE NO. 2		-7,000							
SAMPLE NO. 3		-1,000							
CAPRAN 80									
SAMPLE NO. 1		8,600	7,000	6,600	6,200	5,400	4,800	4,200	
SAMPLE NO. 2		12,800	9,000	8,800	8,000	7,000	6,000	5,200	
SAMPLE NO. 3		11,400	8,600	8,400	8,000	7,200	6,200	5,400	
CAPRAN 512H									
SAMPLE NO. 1		20,000	13,000	2,500	500	LESS THAN 100			
SAMPLE NO. 2		20,000	12,500	2,000	1,000	LESS THAN 100			
SAMPLE NO. 3		21,500	11,500	2,500	1,000	LESS THAN 100			
ELECTRO-SAFE									
SAMPLE NO. 1		350	200	LESS THAN 100					
SAMPLE NO. 2		350	200	LESS THAN 100					
SAMPLE NO. 3		350	200	LESS THAN 100					
LECTROLITE									
SAMPLE NO. 1		LESS THAN 100							
SAMPLE NO. 2		LESS THAN 100							
SAMPLE NO. 3		LESS THAN 100							

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 2 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 71°F RELATIVE HUMIDITY: 46%

MATERIAL	VOLTAGE DISCHARGE RATE*						
	0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC
<u>PRV-1310</u>							
SAMPLE NO. 1	6,800	3,000	600	200	200	200	LESS THAN 100
SAMPLE NO. 2	6,800	3,000	600	200	200	200	"
SAMPLE NO. 3	6,800	3,000	600	200	200	200	"
<u>RCAS 2400</u>							
SAMPLE NO. 1	17,500	13,500	13,000	11,000	9,500	8,000	6,500
SAMPLE NO. 2	20,000	18,500	16,500	12,500	10,000	7,500	6,000
SAMPLE NO. 3	25,000	22,000	19,000	14,500	13,000	11,000	10,000
<u>SARAN 18L</u>							
SAMPLE NO. 1	-5,500						
SAMPLE NO. 2	-5,500						
SAMPLE NO. 3	-3,000						
<u>VELOSTAT FILM</u>							
SAMPLE NO. 1	LESS THAN 100						
SAMPLE NO. 2	LESS THAN 100						
SAMPLE NO. 3	LESS THAN 100						

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 2 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 71°F RELATIVE HUMIDITY: 46%

MATERIAL	VOLTAGE DISCHARGE RATE*						
	0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC
WRIGHTON AS-1400							
SAMPLE NO. 1	18,500	17,500	13,000	9,500	7,500	6,500	5,500
SAMPLE NO. 2	18,500	17,500	15,000	12,000	9,500	8,000	7,000
SAMPLE NO. 3	18,000	17,500	14,500	13,500	12,000	10,000	9,500

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 3
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

		TEMPERATURE: 78°F	RELATIVE HUMIDITY: 37%							
		VOLTAGE DISCHARGE RATE*								
<u>MATERIAL</u>		0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC		
<u>ACIAR</u>										
SAMPLE NO. 1	7,000	3,000								
SAMPLE NO. 2	9,000	600								
SAMPLE NO. 3	4,000	800								
<u>CAPRAN 80</u>										
SAMPLE NO. 1	19,500	15,000	14,500	13,500	11,500	9,500	8,500			
SAMPLE NO. 2	19,500	16,500	15,500	14,000	11,500	9,500	8,500			
SAMPLE NO. 3	18,500	15,500	15,500	15,000	14,500	13,500	12,500			
<u>CAPRAN 512H</u>										
SAMPLE NO. 1	21,000	15,500	5,500	1,000	100					
SAMPLE NO. 2	21,000	15,500	5,500	1,000	100					
SAMPLE NO. 3	23,500	20,000	1,500	3,500	1,500	500	100			
<u>ELECTRO-SAFE</u>										
SAMPLE NO. 1	300	100	LESS THAN 100							
SAMPLE NO. 2	300	100	LESS THAN 100							
SAMPLE NO. 3	300	100	LESS THAN 100							
<u>LECTROLITE</u>										
SAMPLE NO. 1	LESS THAN 100									
SAMPLE NO. 2	LESS THAN 100									
SAMPLE NO. 3	LESS THAN 100									

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 3 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

MATERIAL	TEMPERATURE: 78°F		RELATIVE HUMIDITY: 37%		VOLTAGE DISCHARGE RATE*					
	0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC			
PRV 1310										
SAMPLE NO. 1	8,200	5,200	1,000	400	200	LESS THAN 100	—			
SAMPLE NO. 2	8,000	4,000	800	200	200	LESS THAN 100	—			
SAMPLE NO. 3	7,800	4,000	1,000	400	400	200	200			
RCAS 2400										
SAMPLE NO. 1	16,000	14,000	11,000	6,000	3,500	2,000	1,500			
SAMPLE NO. 2	20,000	10,000	2,000	500	500	LESS THAN 100	—			
SAMPLE NO. 3	19,500	10,000	2,500	1,000	1,000	500	500			
SARAN 18L										
SAMPLE NO. 1	4,200	600								
SAMPLE NO. 2	6,400	6,000								
SAMPLE NO. 3	5,400	2,600								
VELOSTAT FILM										
SAMPLE NO. 1	LESS THAN 100									
SAMPLE NO. 2	LESS THAN 100									
SAMPLE NO. 3	LESS THAN 100									

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 3 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 78°F		RELATIVE HUMIDITY: 37%					
<u>MATERIAL</u>	<u>VOLTAGE DISCHARGE RATE*</u>						
	<u>0.35 SEC</u>	<u>0.5 SEC</u>	<u>1.0 SEC</u>	<u>2.0 SEC</u>	<u>3.0 SEC</u>	<u>4.0 SEC</u>	<u>5.0 SEC</u>
<u>WRIGHTON AS-1400</u>							
SAMPLE NO. 1	8,800	7,200	3,800	2,000	1,400	1,200	1,000
SAMPLE NO. 2	8,400	7,300	6,800	5,200	3,800	3,200	2,600
SAMPLE NO. 3	19,000	15,500	8,000	4,000	2,000	1,500	1,000

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 4
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

		TEMPERATURE: 74°F	RELATIVE HUMIDITY: 18%					
		VOLTAGE DISCHARGE RATE*						
<u>MATERIAL</u>		<u>0.35 SEC</u>	<u>0.5 SEC</u>	<u>1.0 SEC</u>	<u>2.0 SEC</u>	<u>3.0 SEC</u>	<u>4.0 SEC</u>	<u>5.0 SEC</u>
<u>ACIAR</u>								
SAMPLE NO. 1		8,000						
SAMPLE NO. 2		3,000	1,400					
SAMPLE NO. 3		7,000						
<u>CAPRAN 80</u>								
SAMPLE NO. 1		9,600	8,800					
SAMPLE NO. 2		4,000	3,400					
SAMPLE NO. 3		3,200						
<u>CAPRAN 512H</u>								
SAMPLE NO. 1		32,000	28,500	27,500	25,000	23,500	21,500	20,000
SAMPLE NO. 2		24,500	23,500	21,500	17,500	14,500	12,500	10,000
SAMPLE NO. 3		30,000	28,500	25,000	20,500	17,000	14,000	12,000
<u>ELECTRO-SAFE</u>								
SAMPLE NO. 1		700	300	LESS THAN 100				
SAMPLE NO. 2		650	250	LESS THAN 100				
SAMPLE NO. 3		600	250	LESS THAN 100				

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 4 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 74°F		RELATIVE HUMIDITY: 18%						
MATERIAL		VOLTAGE DISCHARGE RATE*						
		0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC
<u>LECTROLITE</u>								
SAMPLE NO. 1		LESS THAN 100						
SAMPLE NO. 2		LESS THAN 100						
SAMPLE NO. 3		LESS THAN 100						
<u>PRV 1310</u>								
SAMPLE NO. 1		17,000	11,500	3,500	1,000	500	500	LESS THAN 100
SAMPLE NO. 2		15,000	10,500	3,500	1,000	500	500	"
SAMPLE NO. 3		16,000	11,500	3,500	1,000	500	500	"
<u>RCAS 2400</u>								
SAMPLE NO. 1		17,000	14,500					
SAMPLE NO. 2		12,000	10,000					
SAMPLE NO. 3		14,000	9,500					

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 4 (CONT'D)
ELECTROSTATIC TEST RESULTS
PRIOR TO BEACH EXPOSURE

TEMPERATURE: 74°F RELATIVE HUMIDITY: 18%

MATERIAL	VOLTAGE DISCHARGE RATE*					
	0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	5.0 SEC
<u>SARAN 18L</u>						
SAMPLE NO. 1	1,600	1,200				
SAMPLE NO. 2	1,350	250				
SAMPLE NO. 3	1,500	350				
<u>VELOSTAT</u>						
SAMPLE NO. 1	LESS THAN 100					
SAMPLE NO. 2	LESS THAN 100					
SAMPLE NO. 3	LESS THAN 100					
<u>WRIGHTLON AS-1400</u>						
SAMPLE NO. 1	8,400	7,000	4,600	2,400	1,400	800
SAMPLE NO. 2	12,800	11,200	11,200	11,000	10,500	9,800
SAMPLE NO. 3	11,600	10,000	7,800	5,600	4,400	3,400

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 5
ELECTROSTATIC TEST RESULTS
AFTER BEACH EXPOSURE OF THREE WEEKS

		TEMPERATURE: 74°F		RELATIVE HUMIDITY: 42%					
		VOLTAGE DISCHARGE RATE*							
<u>MATERIAL</u>		<u>0.35 SEC</u>	<u>0.5 SEC</u>	<u>1.0 SEC</u>	<u>2.0 SEC</u>	<u>3.0 SEC</u>	<u>4.0 SEC</u>	<u>5.0 SEC</u>	
<u>ACLAR</u>									
SAMPLE NO. 1 **		4,200	-200	-600	-800	-800	-1,000	-1,000	
SAMPLE NO. 2 **		600	-1,600	-1,800	-2,000	-2,200	-2,400	-2,600	
<u>CAPRAN 80</u>									
SAMPLE NO. 1		23,500	20,500	15,000	8,000	4,000	2,000	1,500	
SAMPLE NO. 2		23,500	20,500	16,000	9,500	5,500	3,500	2,000	
<u>CAPRAN 512H</u>									
SAMPLE NO. 1		22,500	20,000	15,000	8,500	5,000	3,500	1,500	
SAMPLE NO. 2		20,500	18,500	14,000	7,000	3,500	2,000	1,000	
<u>ELECTRO-SAFE</u>									
SAMPLE NO. 1		700	450	350					
SAMPLE NO. 2		500	300						
<u>LECTROLITE</u>									
SAMPLE NO. 1		300	250						
SAMPLE NO. 2		300	250						

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

**TORN BY WIND-USED SMALLER PIECES

TABLE 5 (CONT'D)
ELECTROSTATIC TEST RESULTS
AFTER BEACH EXPOSURE OF THREE WEEKS

		TEMPERATURE: 74°F		RELATIVE HUMIDITY: 42%					
		VOLTAGE DISCHARGE RATE*							
MATERIAL		0.35 SEC	0.5 SEC	1.0 SEC	2.0 SEC	3.0 SEC	4.0 SEC	5.0 SEC	
PRV 1310									
SAMPLE NO. 1		1,350	600	350	300	250	250	200	
SAMPLE NO. 2		2,250	750	350	300	250	250	200	
RCAS 2400									
SAMPLE NO. 1		21,000	18,500	14,500	8,500	5,000	3,000	2,000	
SAMPLE NO. 2		23,500	21,500	16,500	10,500	6,500	4,000	2,500	
SARAN 18L									
SAMPLE NO. 1		13,000	11,500	11,500	11,000	11,000	11,000	10,500	
SAMPLE NO. 2		16,500	16,000	15,500					
VELOSTAT									
SAMPLE NO. 1		200	150						
SAMPLE NO. 2		200	150						
WRIGHTON AS-1400									
SAMPLE NO. 1		6,000	3,400	1,400	600	400	400	200	
SAMPLE NO. 2		10,200	7,000	5,000	3,600	3,000	2,600	2,000	

*TIME AFTER TERMINATION OF CHARGE APPLICATION.

TABLE 6
FLAMMABILITY TESTING RESULTS OF PLASTICS
TEST METHOD: NHB 8060.1A TESTS NO. 1 AND NO. 2

MATERIAL	FLAME CHARACTERISTICS	BURN LENGTH (IN.)	BURN TIME (SEC)	REMARKS
<u>ACLAR MANUFACTURED BY THE ALLIED CHEMICAL COMPANY</u>				
TEST NO. 1	SELF-EXTINGUISHED	3.2	20	MET THE SPECIFICATION
TEST NO. 2		0.7	"	
<u>CAPRAN 80 MANUFACTURED BY THE ALLIED CHEMICAL COMPANY</u>				
TEST NO. 1	"	3.7	"	"
TEST NO. 2	"	0.6	"	"
<u>CAPRAN 512H MANUFACTURED BY THE ALLIED CHEMICAL COMPANY</u>				
TEST NO. 1	"	3.6	"	"
TEST NO. 2	"	0.8	"	"
<u>ELECTRO-SAFE MANUFACTURED BY THE WILSON SALES COMPANY</u>				
TEST NO. 1	"	6.3	51	THE MATERIAL IGNITED, E CONSIDERABLE BLACK SMO AVERAGE OF 6.3 INCHES, THE REMAINDER OF THE TE THE MATERIAL FAILED THE REQUIREMENTS FOR GROUP
TEST NO. 2	"	0.9	20	MET THE SPECIFICATION

TABLE 6 (CONT'D)
 FLAMMABILITY TESTING RESULTS OF PLASTICS
 TEST METHOD: NHB 8060.1A TESTS NO. 1 AND NO. 2

MATERIAL	FLAME CHARACTERISTICS	BURN LENGTH (IN.)	BURN TIME (SEC)	REMARKS
<u>LECTROLITE MANUFACTURED BY</u> <u>HERCULITE PRODUCTS,</u>				
TEST NO. 1	SELF-EXTINGUISHED	4.0	20	MET THE SPECIFICATION
TEST NO. 2		0.7	"	
<u>PRV 1310 MANUFACTURED BY</u> <u>THE SNYDER MANUFACTURING</u> <u>COMPANY</u>				
TEST NO. 1	"	4.6	"	"
TEST NO. 2	"	0.7	"	"
<u>RCAS-2400 MANUFACTURED BY</u> <u>THE RICHMOND CORPORATION</u>				
TEST NO. 1	"	3.7	"	"
TEST NO. 2	"	0.7	"	"
<u>SARAN 18L MANUFACTURED BY</u> <u>THE DOW CHEMICAL</u>				
TEST NO. 1	"	5.0	"	"
TEST NO. 2	"	0.6	"	"

TABLE 6 (CONT'D)
 FLAMMABILITY TESTING RESULTS OF PLASTICS
 TEST METHOD: NHB 8060.LA TESTS NO. 1 AND NO. 2

MATERIAL	FLAME CHARACTERISTICS	BURN LENGTH (IN.)	BURN TIME (SEC)	REMARKS
<u>VELOSTAT FILM MANUFACTURED BY THE 3M COMPANY</u>				
TEST NO. 1	BURNING	—	—	THE MATERIAL IGNITED AND BURNED COMPLETELY AT A RATE OF ABOUT 24 INCHES PER MINUTE. THE MATERIAL FAILED THE FLAMMABILITY REQUIREMENTS FOR GROUP I APPLICATIONS.
TEST NO. 2	"	—	—	THE MATERIAL IGNITED AND BURNED COMPLETELY AT A RATE OF ABOUT 1 INCH PER MINUTE. THE MATERIAL FAILED THE FLAMMABILITY REQUIREMENTS FOR GROUP I APPLICATIONS.
<u>WRIGHTLON AS-1400 MANUFACTURED BY INTERNATIONAL PLASTIC PRODUCTS, INCORPORATED</u>				
TEST NO. 1	SELF-EXTINGUISHED	6.2	30	THE MATERIAL DRIPPED FLAMING PARTICLES IN TEST NO. 1 AND TEST NO. 2 THE MATERIAL FAILED THE REQUIREMENTS FOR GROUP I APPLICATIONS.
TEST NO. 2	"	2.3	33	"

TABLE 7

TEST HYPERGOLIC FLUID COMPATIBILITY OF PLASTICS

METHOD: FIVE MINUTES LIQUID EXPOSURE TO ONE SIDE ONLY

MATERIAL	OBSERVED REACTIONS		
	N_2O_4	N_2H_4	MMH
<u>ACLAR</u>	NO REACTION	NO REACTION	NO REACTION
<u>CAPRAN 80</u>	MATERIAL DISSOLVED	"	"
<u>CAPRAN 512H</u>	"	"	"
<u>ELECTROSAFE</u>	EXPOSED AREA BECAME SLIGHTLY YELLOW.	"	EXPOSED AREA BECAME OPAQUE.
<u>LECTROLITE</u>	COLOR CHANGED FROM BLUE TO VIOLET. MATERIAL WRINKLED, BUBBLED, BECAME SLIGHTLY TACKY AND HARD. NO VIOLENT REACTIONS WERE OBSERVED.	"	SLIGHT DISCOLORATION, NO OTHER REACTION OBSERVED.
<u>PRV 1310</u>	MATERIAL CHANGED COLOR ON BOTH SIDES FROM GREEN TO YELLOW. MATERIAL BECAME HARDER AND SOME PITTING WAS OBSERVED.	"	SLIGHT DISCOLORATION OF EXPOSED AREA.

TABLE 7 (CONT'D)

TEST HYPERGOLIC FLUID COMPATIBILITY OF PLASTICS

METHOD: FIVE MINUTES LIQUID EXPOSURE TO ONE SIDE ONLY

MATERIAL	OBSERVED REACTIONS		
	N_2O_4	N_2H_4	MMH
<u>RCAS 2400</u>	SAMPLE PARTIALLY DISSOLVED. REMAINING PORTION WAS VERY TACKY AND SHOWED SOME SIGN OF CRUMBLING.	SLIGHT CLOUDINESS IN EXPOSED AREA.	SLIGHT CLOUDINESS AROUND PERIMETER OF EXPOSED AREA.
<u>SARAN 18L</u>	SLIGHT CLOUDINESS IN THE EXPOSED AREA.	NO REACTION	EXPOSED AREA BECAME AMBER IN COLOR.
<u>VELOSTAT FILM</u>	NO REACTION	"	NO REACTION
<u>WRIGHTLON AS-1400</u>	"	SLIGHT CLOUDINESS DEVELOPED IN EXPOSED AREA, NO OTHER REACTIVITY	"

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